THE DIET OF BLACK-BACKED JACKAL (*CANIS MESOMELAS*) ON TWO CONTRASTING LAND-USE TYPES IN THE EASTERN CAPE PROVINCE, SOUTH AFRICA AND THE VALIDATION OF A NEW ANALYTICAL METHOD OF MAMMALIAN HAIR IDENTIFICATION

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ABSTRACT

Diet assessments are critical for understanding the foraging behaviour, habitat use and trophic separation of mammalian predators and are vital for gaining insight into how predators influence prey populations. The aim of this research was to qualitatively describe the diet of black-backed jackals (*Canis mesomelas*, Schreber 1775) using scat analysis on two contrasting land-use types in the Eastern Cape Province, South Africa. Scats were collected on a monthly basis from November 2009 to October 2010 from two game reserves (Great Fish River Reserve and Shamwari Private Game Reserve) and two neighbouring livestock farms.

The relative frequency of occurrence of mammal hair (33 – 47 %) and vegetation (32 – 45%) dominated jackal diet throughout the year across the four study sites. Other important prey items included invertebrates (8 – 21 %) and fruit and seeds (3 – 11 %). Birds and reptiles constituted ≤ 2 % of the diet and were only recorded on the game reserves. Significant seasonal dietary shifts were observed on the game reserves but not on the farms. Fruit and seeds were significantly more frequent in the diet during autumn at Great Fish River Reserve and invertebrates were significantly less common in the diet during winter on both reserves. In addition, vegetation was significantly more common in the diet during winter at Shamwari Private Game Reserve. The significant temporal variation of certain prey items is testament to black-backed jackals being opportunistic generalists, foraging on those food items which are most abundant, accessible and energetically beneficial.

Land-use type also influenced the diet of black-backed jackals with significantly more invertebrates and, fruit and seeds being recorded on the game reserves than on the farms. By contrast, significantly more mammal hair and vegetation were present in the diet on the farms compared with the game reserves. The mammalian component of the diet was dominated by ruminants and rodents on the game reserves and by ruminants and livestock on the farms. The presence of livestock in the diet of black-backed jackals on the farms highlights their potential impact on the livestock industry in the region and may assist farmers in determining which predators are responsible for stock loss.

Previous approaches for identifying mammalian hairs from predator scats have utilised dichotomous keys and reference collections but these are often time-consuming and require a trained individual to carry out the identification. Thus, I also tested the efficacy of an automated pattern recognition programme (*HairSnap*) for identifying mammalian hairs from black-backed jackal scats. The overall accuracy of the programme was 38 % with black-backed jackal, Greater kudu (*Tragelaphus strepsiceros*) and striped polecat (*Ictonyx striatus*) hairs being accurately identified more often (70 – 80%) than any other species tested. It is likely that both the size and species composition of the sample resulted in the poor accuracy of the programme. However, with the implementation of several improvement measures (e.g. adjustment of the algorithm) the programme may offer a superior, bias-free method of mammalian hair identification.

The dietary information gathered here furthers our knowledge of the biology of the black-backed jackals, especially in the locally important thicket biome. Moreover, understanding their

foraging habits allows for more effective management of the species on both game reserves and farmlands. I recommend that future research should focus on quantitatively assessing the diet of black-backed jackals in the Eastern Cape Province and elsewhere. This will compliment the dietary description provided in this study and may offer a biologically more meaningful indication of the relative importance of the prey items.

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TABLE OF CONTENTS

Chapter 1: *GENERAL INTRODUCTION*

Chapter 2: *GENERAL DESCRIPTION OF THE STUDY SITES*

CHAPTER 1

GENERAL INTRODUCTION

1.1 THE BIOLOGY OF THE BLACK-BACKED JACKAL

Physical description

The black-backed jackal (Canidae: *Canis mesomelas mesomelas,* Schreber 1775) is a slender, long-legged jackal with large, usually erect ears and a long, pointed muzzle typical of the Canidae family (Figure 1.1; Smithers 1983; Kingdon 1997; Mills & Hes 1997; Walton & Joly 2003; Loveridge & Nel 2004; Skinner & Chimimba 2005). The characteristic feature of the species is the well-defined black saddle intermixed with silvery-grey hair that extends from its broadest point at the nape of the neck tapering along the back to the base of the tail (Smithers 1983; Kingdon 1997; Mills & Hes 1997; Loveridge & Nel 2004; Skinner & Chimimba 2005). The general colouration of the species including the head, ears, flanks, limbs and basal third of the tail are a deep russet red whilst the chest, throat, lips and the inside of the limbs are a contrasting beige to white (Smithers 1983; Walton & Joly 2003; Loveridge & Nel 2004; Skinner & Chimimba 2005). The posterior two thirds of the bushy tail are typically a dark-brown colour culminating in a black tip (Smithers 1983; Mills & Hes 1997; Walton & Joly 2003; Loveridge & Nel 2004). Animals occurring in the eastern regions of the range are typically less vividly coloured with the overall colouration and specifically the face and muzzle tending to be more grey-brown than their western occurring conspecifics (Smithers 1983; Loveridge & Nel 2004; Skinner & Chimimba

2005). This is also true for females which are generally less richly coloured than their male counterparts across the entire range (Smithers 1983; Skinner & Chimimba 2005).

The average mass of adult male black-backed jackals is 8.0 kg (range = 5.0 - 13.5 kg) while the average mass of adult females is 7.3 kg (range = 5.0 - 10.0 kg) (Rowe-Rowe 1978; Rautenbach 1982; Stuart 1981; Smithers 1983; Kingdon 1997; Mills & Hes 1997; Walton & Joly 2003; Loveridge & Nel 2004; Skinner & Chimimba 2005). The shoulder height of adult jackals ranges from 38 to 48 cm (Smithers 1983; Sheldon 1992; Mills & Hes 1997). The species is marginally sexually dimorphic in terms of body size (Smithers 1983; Walton & Joly 2003; Loveridge & Nel 2004; Skinner & Chimimba 2005).

The black-backed jackal is digitigrade and the forefeet have five digits. The first digit carries the dew claw and is set back from the remainder and does not show in the print (Skinner & Chimimba 2005). The hind foot has four digits. The claws are broad at the base and measure approximately 150 mm over the curve (Skinner & Chimimba 2005).

The skull of *C. m. mesomelas* is elongated with a pear-shaped brain case and a narrow rostrum (Walton & Joly 2003; Loveridge & Nel 2004; Skinner & Chimimba 2005). The upper outer incisors are larger, more pointed and more canine-like than those on the lower jaw whilst the upper canines are long and curved to a sharp point (Loveridge & Nel 2004; Skinner & Chimimba 2005). The dentition of the species is well adapted for its omnivorous diet; the canines, assisted by the outer upper incisors, allow for the catching and holding of prey, the carnassial shear for slicing, and the broad molars for the grinding of insects, plant material and other more fragile food items (Skinner & Chimimba 2005).

Figure 1.1: The black-backed jackal *Canis mesomelas* (taken from Mills & Hes 1997).

Taxonomy, phylogeny and conservation status

The black-backed jackal is one of five canid species occurring in the southern African subregion (Skinner & Chimimba 2005). Six subspecies were recognised in the past (Allen 1939); however, subsequent research on their taxonomy by Ellerman *et al.* (1953) and Coetzee (1971) refute such divisions. This classification was adjusted by Meester *et al.* (1986) who assigned all material within the southern African subregion to the subspecies *Canis mesomelas mesomelas* whilst leaving the east African subspecies divided in two. Based on the minor and inconsistent morphological and genetic differences and the lack of a barrier to gene flow within the range of

C. mesomelas Wayne *et al.* (1990) reported that certain subspecies were not warranted and supported the adjusted classification by Meester et al. (1986). This was followed by Kingdon's (1997) recognition of only two geographically isolated subspecies, *Canis mesomelas schmidtii* (East Africa) and *C. m. mesomelas* (Southern Africa).

The International Union for the Conservation of Nature (IUCN) listed the black-backed jackal in 2004 as one of least concern (Loveridge & Nel 2004). There are no recognised major threats to the species despite human persecution due to their predation on livestock and functioning as vectors for diseases such as rabies (Walton & Joly 2003; Loveridge & Nel 2004). However, according to Loveridge & Nel (2008), efforts to control their populations appear largely ineffective and probably only succeed in producing a temporary reduction in numbers.

Distribution, status and habitat

The black-backed jackal is endemic to Africa and occurs in two distinctly isolated regions of the continent (Smithers 1983; Walton & Joly 2003; Loveridge & Nel 2004; Skinner & Chimimba 2005). The subspecies, *C. m. schmidtii*, occupies the northern range in east Africa which extends from the Gulf of Aden into Sudan, Eritrea, Ethiopia, and Somalia, and southwards into southern Tanzania (Figure 1.2; Smithers 1983; Sheldon 1992; Walton & Joly 2003; Loveridge & Nel 2004; Skinner & Chimimba 2005). The most western extent of this range is Uganda. *Canis mesomelas mesomelas* inhabits the southern region of the continent including south-west Angola, Namibia, Botswana, the western and central regions of Zimbabwe, and southern Mozambique south of the Save River (Figure 1.2; Smithers 1983; Sheldon 1992; Walton & Joly 2003; Loveridge & Nel 2004; Skinner & Chimimba 2005). They occur throughout Swaziland and in certain regions of

Lesotho. The Mozambique Gap (from the Zambezi River to Tanzania) separates the two ranges of the species by approximately 1000 km (van den Brink 1973). In South Africa they are widespread in all the provinces (Figure 1.2, Stuart 1981; Smithers 1983; Stuart *et al.* 1985).

The species occurs exclusively south of the Sahara and is entirely absent from Zambia and through much of central and equatorial Africa (Ansell 1960; Smithers 1983; Skinner & Chimimba 2005). The disjunct distribution of *C. mesomelas* is similar to that of other species adapted to dry conditions and endemic to Africa including the aardwolf *Proteles cristatus* and the bat-eared fox *Otocyon megalotis* (Smithers 1983; Loveridge & Nel 2004; Skinner & Chimimba 2005). The broad correspondence in distribution between these species indicates that during a drier period in the past there may have been continuity in their distribution (Smithers 1983; Skinner & Chimimba 2005). Moreover, regions of dry *Acacia* bush and savanna, the preferred habitat of these species, may have connected southwest Africa with the eastern regions of the continent (Loveridge & Nel 2004).

Fossil remains of black-backed jackals found in South Africa, Kenya and Tanzania dating back to between 2 and 3 million years ago indicate the species has occupied its range since the early Pleistocene era (Hendey 1974; Savage 1978). Interestingly, no fossil remains have been found north of the Sahara indicating they have always been restricted to their sub-Saharan range (Loveridge & Nel 2004).

The black-backed jackal has an extremely wide habitat tolerance, occurring in the Nama-Karoo, Succulent Karoo and Savanna biomes in areas with a mean annual rainfall of approximately 1000mm (Smithers 1983; Mills & Hes 1997; Loveridge & Nel 2004; Skinner & Chimimba 2005).

They are found in arid coastal deserts (Avery *et al.* 1987; Nel *et al.* 1997), montane grasslands (Rowe-Rowe 1982a), open savanna (Fuller *et al.* 1989; Kingdon 1997), woodland savanna mosaics (Loveridge & Macdonald 2002), and on farmland (van der Merwe 1953a; Bothma 1971a; Bussiahn 1997; Loveridge & Maconald 2004; van der Merwe *et al.* 2009). They are absent from the forest biome and tend to occur in more open terrain (Smithers 1983; Kingdon 1997; Mills & Hes 1997; Nel *et al.* 1997; Loveridge & Nel 2004; Skinner & Chimimba 2005). In KwaZulu-Natal they have been recorded to occur from the coast to more than 3000 m above sea level at the summit of the Drakensberg (Rowe-Rowe 1992). Although they are usually more common in the drier regions of their range (Smithers 1983; Loveridge & Nel 2004; Skinner & Chimimba 2005) they have been recorded in localities receiving more than 2000mm of annual rainfall (Rowe-Rowe 1982b).

The black-backed jackal occurs in sympatry with the golden *Canis aureus* and side-striped *Canis adustus* jackals in certain parts of its east African range including Kenya and Ethiopia (Loveridge & Nel 2004; Skinner & Chimimba 2005). The golden jackal replaces the black-backed jackal to the north in parts of the Middle East, Europe and southern Asia. In addition, the black-backed jackal occurs in sympatry with the side-striped jackal in its southern range in parts of Zimbabwe, Botswana and South Africa (Loveridge & Nel 2004). Both the golden and side-striped jackals typically lack the characteristic prominent dark saddle of *C. m. mesomelas*, although it is sometimes apparent in the golden jackal. They also lack the reddish limbs and flanks. The side-striped jackal is distinguished by a white stripe along the flanks and sides, and has a characteristic white-tipped tail. The golden jackal is characterised by an overall sandy-brown colouration and cream-coloured under parts (Loveridge & Nel 2004).

According to Loveridge & Nel (2004), where more than one jackal species occur in sympatry the habitat is partitioned. Black-backed jackals are sympatric with the side-striped jackal *C. adustus* in the most eastern limits of their southern African range (central and western Zimbabwe) and show a preference for open grassland habitat whilst *C. adustus* shows a tendency to occupy woodland and ecotone areas (Smithers 1983; Loveridge & Macdonald 2002; Loveridge & Macdonald 2003; Skinner & Chimimba 2005). The majority of the habitat partitioning in this case appears to be mediated by aggressive interactions in which *C. m. mesomelas* displaced *C. adustus* from grassland habitats (Loveridge & Macdonald 2002). This is the only region in their southern African distribution where they are sympatric with another jackal species. Where the three jackal species are sympatric (East Africa), segregation of habitat and temporal activity limit inter-specific competition (Fuller *et al.* 1989). On the Serengeti plains of Tanzania, golden and black-backed jackals use different habitats; *C. mesomelas* typically inhabit the brush woodlands / wooded savanna whereas *C. aureus* inhabit the adjacent short-grass plains (Moehlman 1983; Fuller *et al.* 1989). Moreover, whelping seasons differ with *C. mesomelas* whelping during the dry season (July-September) whilst *C. aureus* gives birth during the wet season (December-March). Although the diets of the two species are similar, inter-specific dominance relationships between the two species vary (Wyman 1967; Lamprecht 1978).

Black-backed jackals are locally common throughout their widespread range but there remain very few regional abundance estimates (Loveridge & Nel 2004). Rowe-Rowe (1982a) recorded densities of one individual per 2.5-2.9 km^2 in the KwaZul-Natal Drakensberg whilst Hiscocks & Perrin (1988) reported up to 22 individuals per 1 km^2 along the Namibian coastline. This extremely varied jackal density is primarily dependent on prey abundance and distribution (Rowe-Rowe 1984; Hiscocks & Perrin 1988; Nel *et al.* 1997).

Diet

Please see *Chapter 3* for a detailed description of the diet of the black-backed jackal.

Behaviour and habits

Black-backed jackals exhibit both nocturnal and diurnal activity (Smithers 1983; Walton & Joly 2003; Loveridge & Nel 2004) but are particularly active during the crepuscular periods of the day (Stuart 1976; Ferguson *et al.* 1988; Walton & Joly 2003). They have a bigeminus circadian activity pattern; the majority of activity occurring in the early evening followed by a second but less intense peak in the early hours of the morning (Rowe-Rowe 1983; Ferguson *et al.* 1988). This pattern closely resembles the activity patterns of important prey items, particularly rodents such as the vlei rat *Otomys irroratus* (Rowe-Rowe 1983; Ferguson *et al.* 1988; Walton & Joly 2003). Periods of intermediate nocturnal light conditions due to moon phase see a marked increase in their activity whilst new and full moon phases are associated with a decrease in activity (Ferguson *et al.* 1988; Walton & Joly 2003). This is due to there being adequate light for hunting during intermediate light conditions whilst simultaneously not compromising their cover. During the new moon phase, there is insufficient light available for the jackal to adequately see resulting in a decrease in activity. During the full moon phase, there is too much light and this compromises their camouflage resulting in a decrease in activity. In areas where they are heavily persecuted by man they become strictly nocturnal (Stuart 1981; Ferguson *et al.* 1988; Hiscocks & Perrin 1988; Fuller *et al.* 1989).

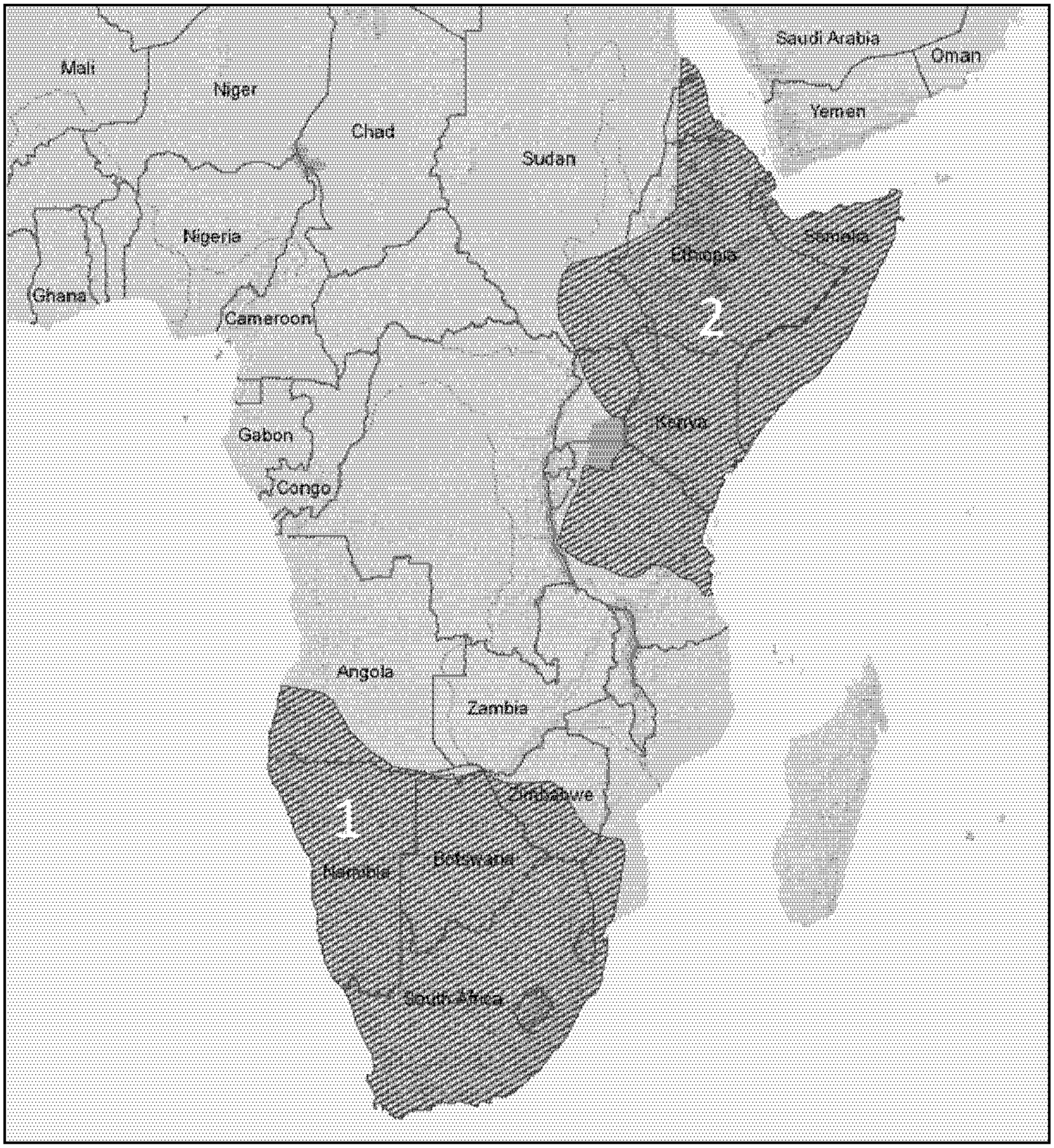

Figure 1.2: The distribution of *Canis mesomelas*: 1, *Canis mesomelas mesomelas*; 2, *Canis mesomelas schmidtii* (taken from Loveridge & Nel 2008).

Black-backed jackals normally forage singly or in pairs but may move around in family parties consisting of the dominant parent pair and sub-adult young (typically five individuals) from that year (Skinner & Chimimba 2005). However, aggregations of up to 10 individuals have been observed at herbivore carcasses (Skinner & Chimimba 2005) and more than 70 individuals have been reported at seal colonies and carcasses on the west coast of Namibia (Stuart 1976; Nel *et al.* 1997).

The hunting methods employed by black-backed jackals when hunting larger wild ungulates are varied and appear to have only been sufficiently observed and documented in East Africa (Wyman 1969) and Botswana (McKenzie 1990). According to Wyman (1969), black-backed jackals hunt Thomson's gazelle *Eudorcas thomsonii* by trotting towards the individuals, gradually increasing in speed to a gallop before grabbing the prey at any available part such as the rear flank, neck or muzzle. The kill is then primary achieved by a suffocating bite to the throat. The other individuals involved in the hunt may, however, kill the animal by tearing open the abdomen before suffocation can take place (Wyman 1967; Lamprecht 1978). This method differs from that employed when hunting impala *Aepyceros melampus* where black-backed jackals, foraging singly or in pairs, will begin the hunt by testing the herd for weakened or young individuals by suddenly rushing towards them and forcing them to take fright and run off (McKenzie 1990). If a compromised individual is located, several jackals may congregate and corner the impala in thick bush before seizing it by the throat and suffocating it (McKenzie 1990).

Movement is normally at a trot when foraging except when hunting for small invertebrates and vertebrates when they walk around slowly with ears erect before pouncing (Smithers 1983;

Skinner & Chimimba 2005). They make use of their hearing and vision when searching for food but are more dependent on their extremely acute sense of smell (Smithers 1983).

The black-backed jackal is described as a social species whose society is made up of a hierarchical family group containing the dominant territorial mated pair, the progeny of the year, non-breeding helpers, and solitary non-breeding, non-territorial individuals (Rowe-Rowe 1982a; Kingdon 1997; Walton & Joly 2003; Loveridge & Nel 2004). The size of the group may range from one to eight animals and can vary seasonally (Rowe-Rowe 1982a). The dominant pair is territorial and scent mark using faeces or urine on conspicuous objects such as grass tufts, small shrubs, rocks and dung piles / middens of other animals to demarcate the boundaries (Moehlman 1978; Ferguson *et al.* 1983; Smithers 1983; Hayward & Hayward 2010). According to Asa *et al.* (1985), canid faeces are a major communicative signal. This olfactory communication is advantageous in that it is effective at night and in areas where visibility is limited (*e.g*. dense thicket vegetation), and remains active for long periods in the absence of the signaller (Gorman & Trowbridge 1989). Moreover, these long-term olfactory cues do not require continued energy expenditure from the sender (Hayward & Hayward 2010). According to Moehlman (1978), jackal pairs foraging together scent mark twice as often as solitary foragers serving to advertise the residence of both sexes within the territory.

Territories are spatially and temporally relatively stable and intruders are aggressively dealt with by territory holders (Loveridge & Nel 2004). Moehlman (1978) recorded that if the territorial pair encountered a trespasser, the same sex of the dominant pair would take action and threaten it whilst the other sex stood aside and observed. There is little or no overlap occurring amongst territorial pairs (Rowe-Rowe 1982a) except in areas where food or water resources are clumped and surrounded by a homogeneous habitat, such as the Namib Desert (Ferguson *et al.* 1983; Hiscocks & Perrin 1988). Furthermore, adult jackals may also make occasional forays into neighbouring territories in search of food, and at large food resources such as carcasses, are well tolerated by the resident pair (Skinner & Chimimba 2005).

The adult home range size of this species varies considerably within its distribution. Rowe-Rowe (1982a) reported the average home range size of adult black-backed jackal in the Giant's Castle Game Reserve, KwaZulu-Natal to be 18.2 km^2 (n = 14). In western Zimbabwe, home ranges were considerably smaller and varied from 0.3 to 1.3 km^2 (mean = 1.1 km^2; n = 13; Loveridge & Macdonald 2001). Fuller *et al.* (1989) reported a slightly larger minimum seasonal home range size for adults in Kenya to vary between 0.7 and 3.5 km^2 (mean = 1.8 km^2; Fuller *et al.* 1989). In the more arid south-western Kalahari, Ferguson *et al.* (1983) reported adult home range sizes to vary from 2.6 to 5.2 km^2 (mean = 4.3 km^2; n = 7) and sub-adult ranges to vary from 4.0 to 8.8 km^2 (mean = 6.3 km^2; n = 4). Hiscocks & Perrin (1988) reported the mean adult home range size in the Cape Cross Seal Reserve on the arid coastline of Namibia to be 24.9 km^2 (range = 17.6 - 34.0 km^2); the largest in the southern African subregion. The large degree of variability in adult home range size can be attributed to a number of factors including differences in topography, habitat type, season, food availability and mating season (Hiscocks & Perrin 1988; Loveridge & Macdonald 2001; Skinner & Chimimba 2005). The age of the animal also affects its home range size where sub-adult jackals may appropriate those of their parents if they are to remain as helpers whilst dispersing sub-adults will move within a far more extensive area (Bothma 1971c; Ferguson *et al.* 1983; Loveridge & Macdonald 2001; Skinner & Chimimba 2005).

Reproduction

Black-backed jackals are reportedly monogamous with a pair bond that may be lifelong (Moehlman 1978; Smithers 1983; Walton & Joly 2003; Loveridge & Nel 2004; Skinner & Chimimba 2005). The onset of mating is associated with increased vocalisation and territoriality (Bernard & Stuart 1992; Loveridge & Macdonald 2001). In southern Africa mating generally occurs from late May to August and is followed by a gestation period of 60-65 days (van der Merwe 1953a; Bernard & Stuart 1992; Mills & Hes 1997; Loveridge & Nel 2004; Skinner & Chimimba 2005). The dominant individuals within a territory are the sole breeders and will prevent the subordinates from mating by persistent harassment (Loveridge & Nel 2004). Parturition occurs from July to October (Bernard & Stuart 1992; Mills & Hes 1997; Skinner & Chimimba 2005) but varies regionally (van der Merwe 1953a; Mills & Hes 1997) and is likely related to habitat and food availability (Moehlman 1978; Bernard & Stuart 1992). The females litter in holes underground, termitaria, or, very often, disused burrows which they modify to suit their requirements (Smithers 1983; Mills & Hes 1997; Walton & Joly 2003). They may change dens regularly if disturbed (Skinner & Chimimba 2005). Females generally give birth to three pups but postnatal litter size may range from one to six individuals (Mills & Hes 1997; Loveridge & Nel 2004; Skinner & Chimimba 2005). Pups are born blind and begin to open their eyes after eight to 10 days (van der Merwe 1953a; Moehlman 1978). However, they will only emerge from the den after three weeks (Moehlman 1978).

Both males and females take part in the rearing and feeding of the young (Smithers 1983). Food is initially regurgitated by both parents for the young; however, after weaning at eight to nine weeks of age it is carried back to the den in their mouths to be left for the young to eat inside or at the entrance to the burrow (Smithers 1983; Loveridge & Nel 2004). The pups will only leave the confines of the den to forage with their parents after 12-14 weeks (van der Merwe 1953a; Smithers 1983). Alloparental care by the previous year's young has been documented for this species in east Africa where the presence of helpers is positively correlated with pup survival (Moehlman 1978). Helpers are usually non-breeding, adult siblings approximately 11-20 months old (Walton & Joly 2003). The helpers regurgitate food for the litter and suckling mother, and guard the pups when the parents are absent allowing them more forage time (Smithers 1983). The alloparents also groom and play with the young, and assist in teaching them to hunt. Once the young begin foraging with their parents, they no longer make use of dens but rather hide in thick vegetation when necessary. The pups reach sexual maturity at about 11 months and will either disperse from the natal range at approximately one year of age or remain in the territory and assist the dominant pair in raising the litter of the following year (van der Merwe 1953a; Ferguson *et al.* 1983; Loveridge & Macdonald 2001). The dispersing individuals have been documented to move more than 100km in search of an appropriate territory to occupy (Bothma 1971c; Ferguson *et al.* 1983).

Impact on livestock

The Eastern Cape in South Africa has been a livestock farming stronghold since the turn of 19th century, the industry being dominated by small-stock farming including Merino and Dorper sheep, and Angora goats (Beinart 1998; van Sittert 1998). The development of this mutton, wool and mohair producing industry was historically associated with the expanding eastward frontier movement of settlers from the Cape at the beginning of the 19th century. The midland

and eastern districts of the Cape were referred to as the heartland of settler small-stock pastoralism, grazing between 30 and 50 % of the colony's small-stock between 1889 and 1910 (van Sittert 1998). The value of wool exports peaked at over £3 million in 1872 and had climbed to a high of £20 million by 1919 (Beinart 1998). The associated mutton industry saw less fluctuation over this period but was still valued at around £3.5 million (Beinart 1998; van Sittert 1998).

The industry was faced with many challenges including disease, environmental damage due to overgrazing and predation by wild carnivores (Beinart 1998; van Sittert 1998). In the last third of the 19th century predators were estimated to take approximately 5-12 % of total small stock annually to the value of £1.6 million. Although there remained a paucity of official statistics on stock predation and predator population sizes, which allowed for great speculation by farmers, this problem seemed to loom disproportionately large compared with disease, reduced grazing on finite pastures and the harshness of the environment (Beinart 1998; van Sittert 1998).

The Cape abounded with predators including lion *Panthera leo*, leopard *Panthera pardus*, cheetah *Acinonyx jubatus*, caracal *Caracal caracal*, African wild cat *Felis* silvestris, brown hyaena *Parahyaena brunnea*, spotted hyaena *Crocuta crocuta*, African wild dog *Lycaon pictus* and the black-backed jackal, all of which were declared vermin for their alleged predilection for domestic stock (Beinart 1998; van Sittert 1998; Skead 2007). In order to reduce depredation by these animals, a variety of methods were employed. Beginning in the early 19th century, hunting with dogs, the setting of steel-jawed gin- and box-traps, and the use of poisons such as strychnine were all employed as means of eradication. In addition, there were a variety of bounty systems introduced by regional agricultural councils and the state to remunerate those individuals who eliminated vermin (Beinart 1998; van Sittert 1998). However, there was one predator that was particularly despised by farmers due to its extremely opportunistic ability to prey on livestock and its capability of surviving through extensive population control efforts; the black-backed jackal (Beinart 1998; van Sittert 1998). This species was described as the "South African farmers' very worst enemy"; "the greatest curse of the small-stock farmer" (van Sittert 1998).

Between 1889 and 1908, over 350 000 individual black-backed jackals were reportedly killed in the Cape (van Sittert 1998). However, the official vermin count was grossly understated due to the widespread use of poison and thus many carcasses were not found or reported. What followed was the development and proliferation of vermin-proof fencing. Stock losses within flocks bound by vermin-proof fencing were greatly reduced and if a predator got into the enclosure, it was much easier to hunt down (Beinart 1998).

In 2008 the National Wool Grower's Association (NWGA) of South Africa reported that annual small-stock losses due to predation were estimated at 1.1 billion ZAR (de Wet 2008). The agricultural sector, particularly the small-stock industry, remains an integral part of the Eastern Cape, and contributes significantly to the South African economy (the income of the Eastern Cape small-stock industry totalled ≈R 139 million in 1980/1981 alone, constituting approximately 56 %, 8 % and 79 % of the wool, mutton and mohair industries gross income respectively in South Africa) (Roux & van der Vyver 1988). Although the methods of eradication have become more advanced since the turn of the 20th century with the development of various poisons, more effective traps and more efficient trap setting, the problem of livestock predation persists. This is primarily due to the predator's opportunistic behaviour and ability to adapt to a changing environment (Smithers 1983; Skinner & Chimimba 2005). This is combined with the lack of 100 % effective predator-proof fencing being available to farmers, and a lack of cooperation among land owners regarding the construction and maintenance of appropriate fencing.

In the last twenty years the Eastern Cape has seen a marked shift in the land-use pattern from agriculture and livestock farming to conservation and wildlife ranching (Eloff 1996; Grossman *et al.* 1999; Smith & Wilson 2002; Bissett 2004; Parker 2004; Parker & Bernard 2005; Sims-Castley *et al.* 2005; Bissett 2007; Cousins *et al.* 2008). The move by farmers from predominantly small-stock farming to conservation has in part been motivated by continued decreasing profit margins. Although there remains a paucity of literature describing the status of predator populations in various farming areas, the continued efforts to eradicate the black-backed jackal have not had the desired effect on their populations (Rowe-Rowe & Green 1981; Ferguson 1986; Heard & Stephenson 1987; Beinart 1998; van Sittert 1998). This has reduced the number of small-stock farms and has altered the management policies of the land. Game ranches and conservation areas typically do very little to control predators such as caracal and black-backed jackal as they are no longer killing livestock but rather filling an ecological niche. However, according to the farmers (Webber & Berrington *pers. comm.*), the change in land-use in the area has led to a concentration of the problem on the remaining small-stock farms. In addition, it has been documented that black-backed jackals may move between conservation areas and neighbouring farmlands (van der Merwe 1953b; Kaunda & Skinner 2003; Loveridge & Macdonald 2004).

In order to efficiently reduce the impact of stock predation it is imperative to have the necessary information to formulate effective and practical predator management policies. Knowledge of the biology of the species including aspects such as spatial ecology, population structure and diet are thus fundamental in generating such policies.

1.2 BROAD MOTIVATION

Research on the diet of the black-backed jackal has been extensive outside the borders of South Africa with studies conducted on the arid coast of Namibia (*e.g.* Stuart 1976; Bothma *et al.* 1984; Avery *et al.* 1987; Hiscocks & Perrin 1987; Nel *et al.* 1997), in south-western Botswana (*e.g*. Kaunda & Skinner 2003) and in western Zimbabwe (*e.g*. Loveridge & Macdonald 2003). Research within South Africa is also reasonably well represented (Bothma 1966, 1971b; Rowe-Rowe 1975, 1976; Stuart 1981; Rowe-Rowe 1983; Stuart 1987; van der Merwe *et al.* 2009; Klare *et al.* 2010). However, only three studies assessing black-backed jackal diet have been conducted in the Eastern Cape, *viz.* Hall-Martin & Botha (1980), Bussiahn (1997) and Do Linh San *et al.* (2009). These studies are all limited by a combination of small sample sizes and restricted temporal and spatial scales.

Thus, the need for a study describing the diet of black-backed jackal in the Eastern Cape for at least an entire year, with an adequate sample size on more than one site including two different land-use types (conservation and farmland) is required. In addition, most studies which have assessed the diet of predators have used manual pattern recognition techniques to identify the mammalian prey component (Rowe-Rowe 1983; Hiscocks & Perrin 1987; Capitani *et al.* 2004; Breuer 2005; Glen & Dickman 2006; Marucco *et al.* 2008; Giannatos *et al.* 2009; Liu *et al.* 2010; Klare *et al.* 2010). However, because of the inherent biases associated with this approach, scope exists to test the application of automated pattern recognition systems developed for this purpose (Moore 1988; Oli 1993; Wallis 1993; Meyer *et al.* 1997; Kelly 2001; Meyer *et al.* 2002; Verma *et al.* 2002; Moyo *et al.* 2006; Foster *et al.* 2010).

CHAPTER 2

GENERAL DESCRIPTION OF THE STUDY SITES

2.1 LOCATION

The study was conducted at four sites near Grahamstown in the Eastern Cape, South Africa (Figure 2.1). The sites were selected based on their size, proximity to Grahamstown, similar habitat types and climate, and the presence of black-backed jackals. In addition, a shared boundary fence between each conservation area and neighbouring farmland was also a necessity.

The Great Fish River Reserve complex (GFRR, hereon referred to as Great Fish) is located approximately 35 km to the north-east of Grahamstown (Figure 2.1). Originally it comprised three separate reserves, namely; the Andries Vosloo Kudu Reserve (AVKR) established in 1973, the Double Drift Game Reserve (DDGR) established in 1986 and the Sam Knott Nature Reserve (SKNR) established in 1987. These three reserves are now contiguous, making the GFRR one of the largest conservation areas (~44 500 ha) in the Eastern Cape. My research was conducted in the AVKR section of the reserve (33°07’S, 26°38’E). The second and associated site was Connaught farm (33°10’S, 26°46’E), situated approximately 40 km to the north-east of Grahamstown and 5 km west of Committee’s Drift (Figure 2.1). The farm shares 11.5 km of fence line with the southern boundary of the AVKR. Shamwari Private Game Reserve (hereon referred to as Shamwari) is situated 68 km to the south-west of Grahamstown, along the N2 national road to Port Elizabeth (33°28'S, 26°02'E; Figure 2.1). The fourth and associated study site was Sweetkloof farm (33°25'S, 26°08'E) situated along the eastern boundary of Shamwari. The farm shares at least 18 km of fence line with Shamwari.

2.2 CLIMATE

The climate of the Eastern Cape is fairly complex and forms a transitional zone for a variety of climatic types (Kopke 1988; Stone *et al.* 1998). According to the modified Köppen system, which uses rainfall and temperature as the most important selection criteria, the Eastern Cape can be divided into seven distinct climatic zones (Kopke 1988). However, the highly varied topography within the province complicates climatic conditions resulting in local variations (Stone *et al.* 1998). In addition, aspect and slope can influence local climate. South-facing slopes experience cooler moist conditions, while north-facing slopes are typically warmer and drier (Stone *et al.* 1998).

The study sites are all situated within the region of the Eastern Cape which experiences warm summers and mild winters with occasional frost (Kopke 1988). Particularly hot days with temperatures exceeding 40 °C occur and are usually associated with 'Berg wind' conditions (a hot dry wind blowing from the mountainous interior to the coast due to being trapped under a cold pocket of air on the leeward side of the escarpment).

Due to their close geographical proximity, the climate pattern descriptions for Great Fish and Shamwari were used as surrogates for the Connaught and Sweetkloof farms respectively.

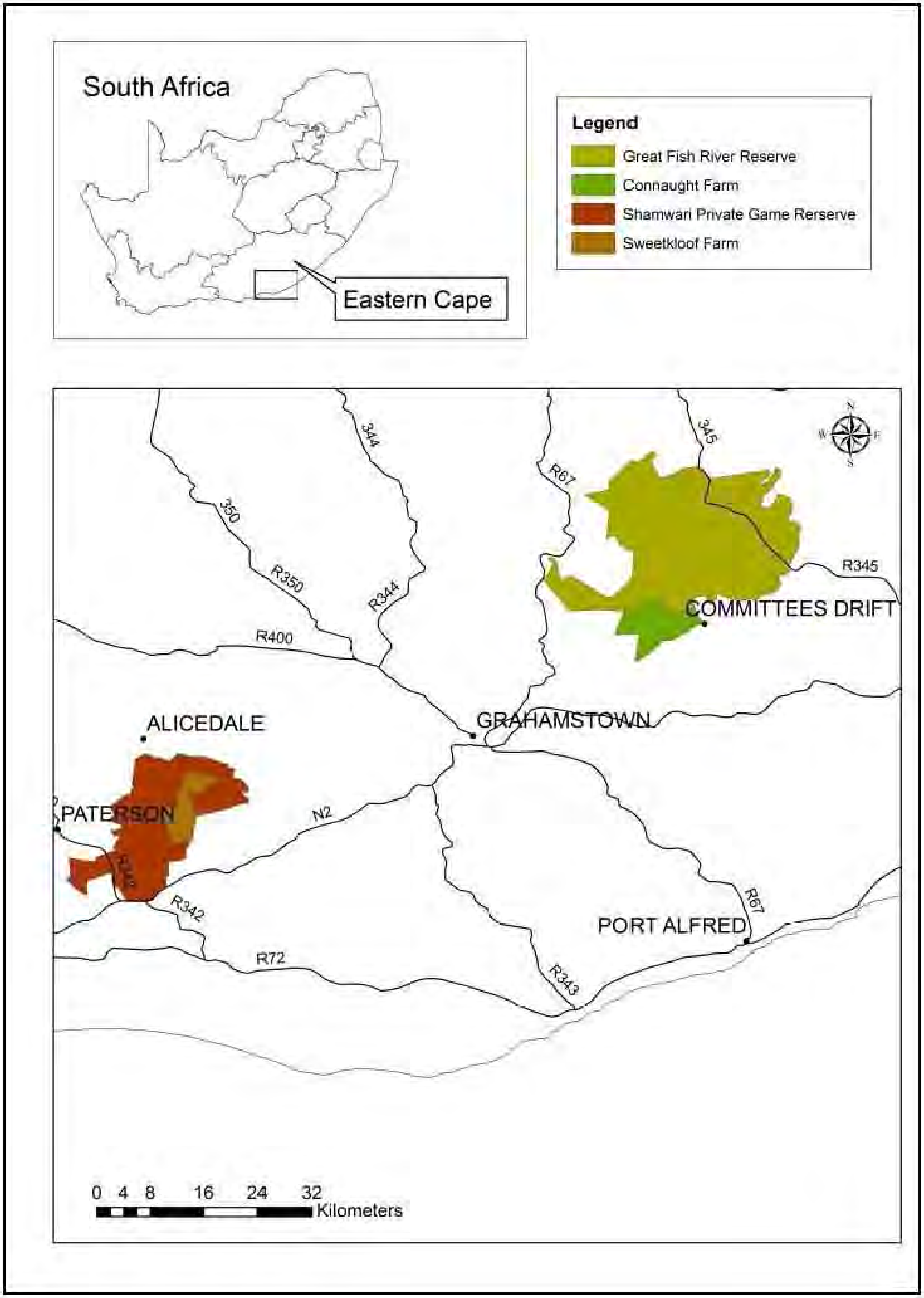

Figure 2.1: The location of the four study sites in the Eastern Cape Province, South Africa (ArcGIS 9; map units: decimal degrees; not projected).

2.3 GREAT FISH RIVER RESERVE

Site description and history

The GFRR was established as a regional game reserve in 1976 and enlarged in 1986 to a total area of 44 500 ha (Do Linh San *et al.* 2009). The AVKR section constitutes 6 500 ha of the total reserve area. The R67 regional road runs parallel to the western boundary of the reserve (Figure 2.1). The eastern boundary borders with the Double Drift and Sam Knott reserves in the vicinity of the perennial Great Fish River. The land was previously utilised for pastoral agriculture, particularly ostrich *Struthio camelus* and small-stock farming. The AVKR is bordered by privately owned small-stock farmland and game farms on the northern, western and southern boundaries. The perennial Great Fish and Kat Rivers form the major water courses in the reserve (Figure 2.2). There are other ephemeral tributaries, some of which are dammed and hold water during wet periods (Brown 2008). As is prescribed for reserves in South Africa that are reintroducing dangerous game (e.g. African elephant *Loxodonta africana*, white *Ceratotherium simum* and black rhino *Diceros bicornis*, Cape buffalo *Syncerus caffer*, and lion *Panthera leo*), the entire perimeter of Great Fish is fenced with electrified game fencing.

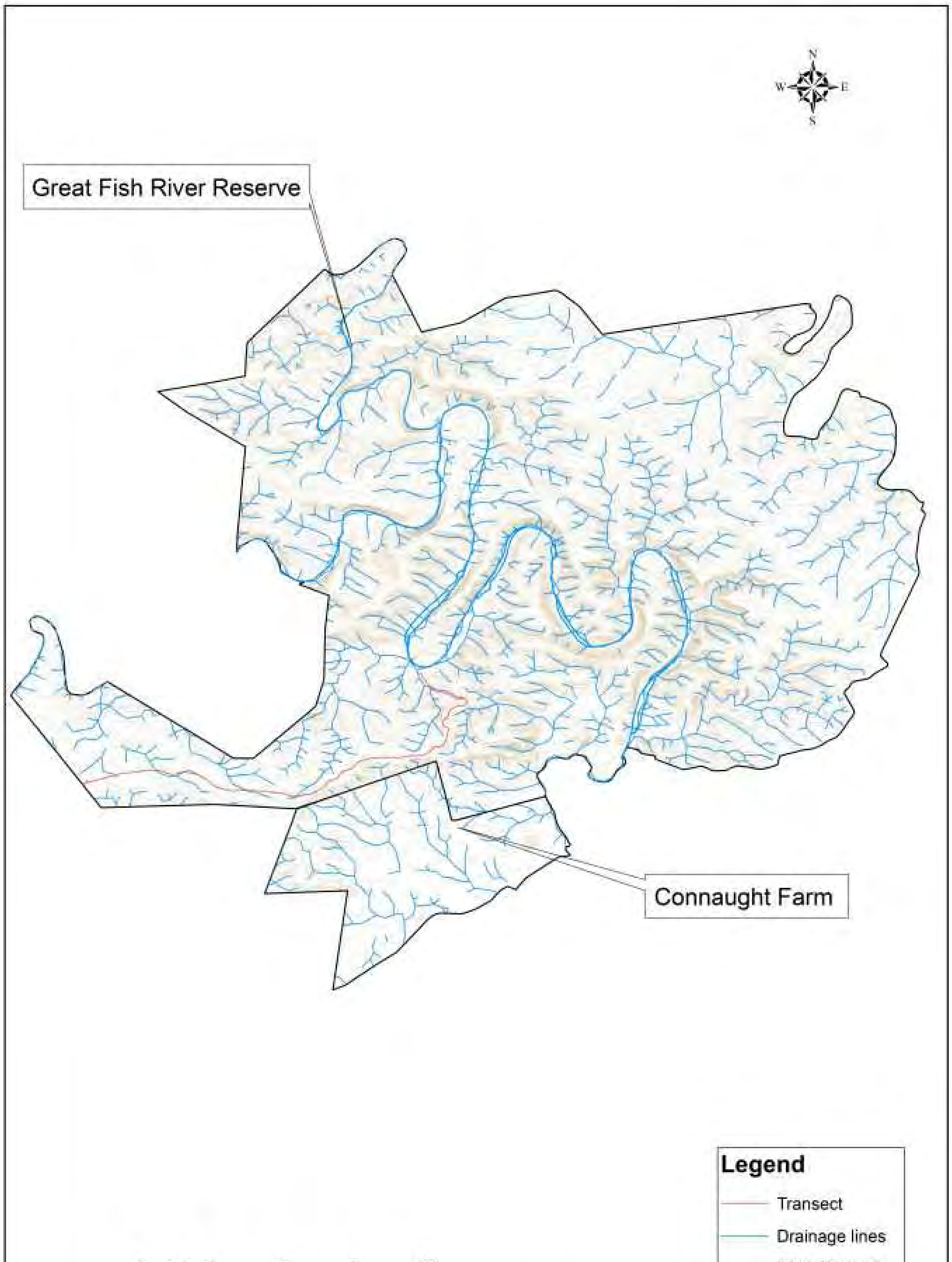

Figure 2.2: The topography and drainage patterns of the Great Fish River Reserve and Connaught farm, and the road transect on the Great Fish River Reserve (ArcGIS 9; map units: decimal degrees; not projected).

Climate

Great Fish has a warm, temperate, semi-arid climate with maximum daily temperatures often exceeding 35 °C in the summer months (December, January and February) and minimum night-time temperatures below -5 °C in the winter months (June, July and August) (Figure 2.4; Schulze 1947; Bussiahn 1997; Brown 2008). The overall mean maximum and minimum temperatures during the study period were 35.7 °C and 6.6 °C respectively. The mean maximum temperature for summer during the study period was 41.8 °C whilst the mean minimum temperature during winter dropped to -0.3 °C. The warmest (43.0 °C) and coldest (-1.0 °C) mean monthly temperatures during the study period were recorded during January and May respectively. The mean monthly temperatures recorded during the study period (2009-2010) were very similar to the ten-year monthly means (Figure 2.3).

There are localised climatic variations on the reserve mainly due to considerable changes in elevation (170 – ≥ 600 m above sea level) between the rivers and the dividing ridges (Do Linh San *et al.* 2009). The lower elevation areas typically experience higher mean annual temperatures and lower mean annual rainfall creating a hot semi-arid environment (Bissett 2004). By comparison, the higher elevation areas experience lower mean annual temperatures and higher mean annual rainfall, resulting in a slightly cooler and wetter environment.

Rainfall events are highly variable at Great Fish and may occur throughout the year with bimodal peaks taking place during the equinox periods (Kopke 1988; Stone *et al.* 1998). The total annual precipitation on Great Fish during the study period was 328.9 mm. This was lower than the ten-year mean (435 ± 76 mm) for the period 1999-2008 (Figure 2.4). The highest monthly rainfall (73.4 mm) for the study period occurred in January 2010 (Figure 2.4). Temperature and rainfall data were recorded from the weather station at the main gate.

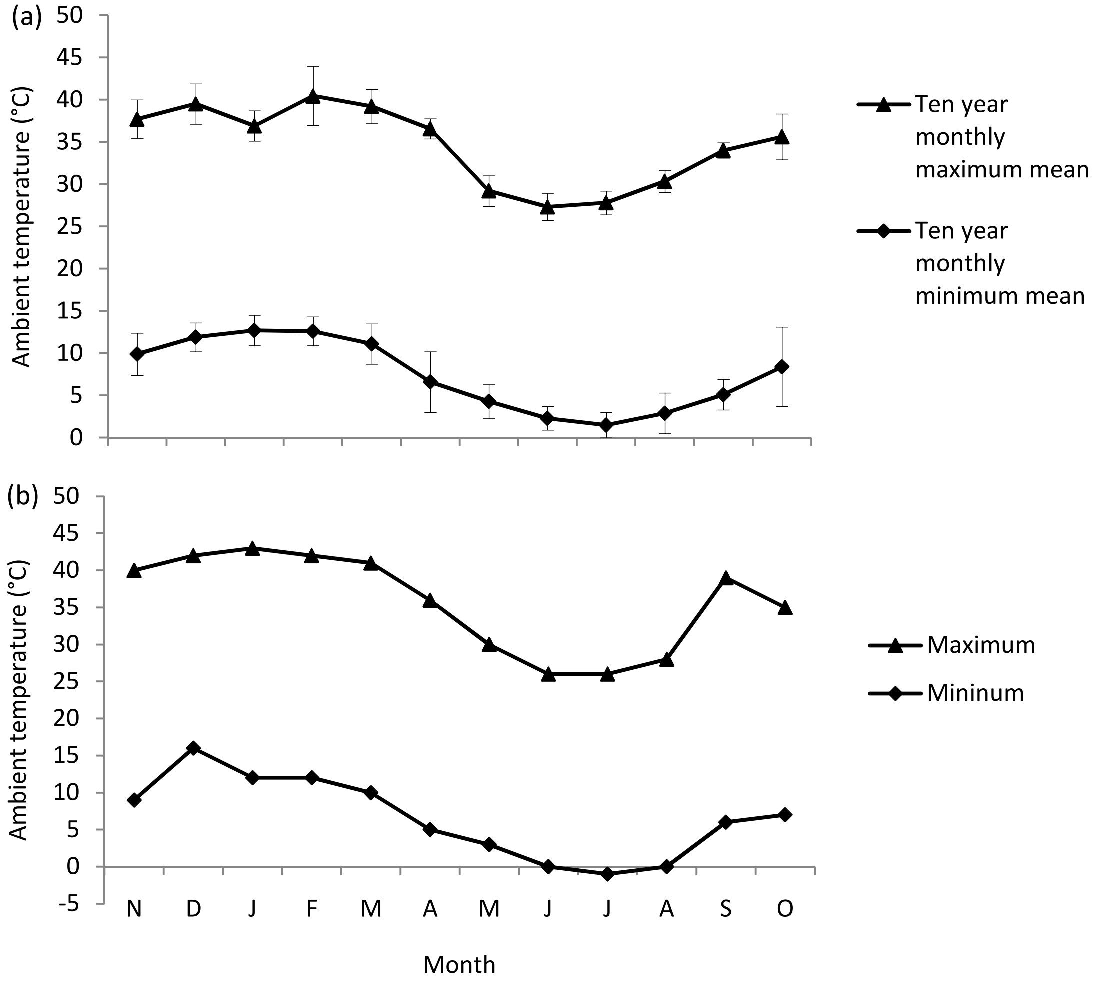

Figure 2.3: The mean (± SD) monthly maximum and minimum temperatures for the Great Fish River Reserve for (a) the ten-year period 1999-2008 and (b) the study period 2009-2010.

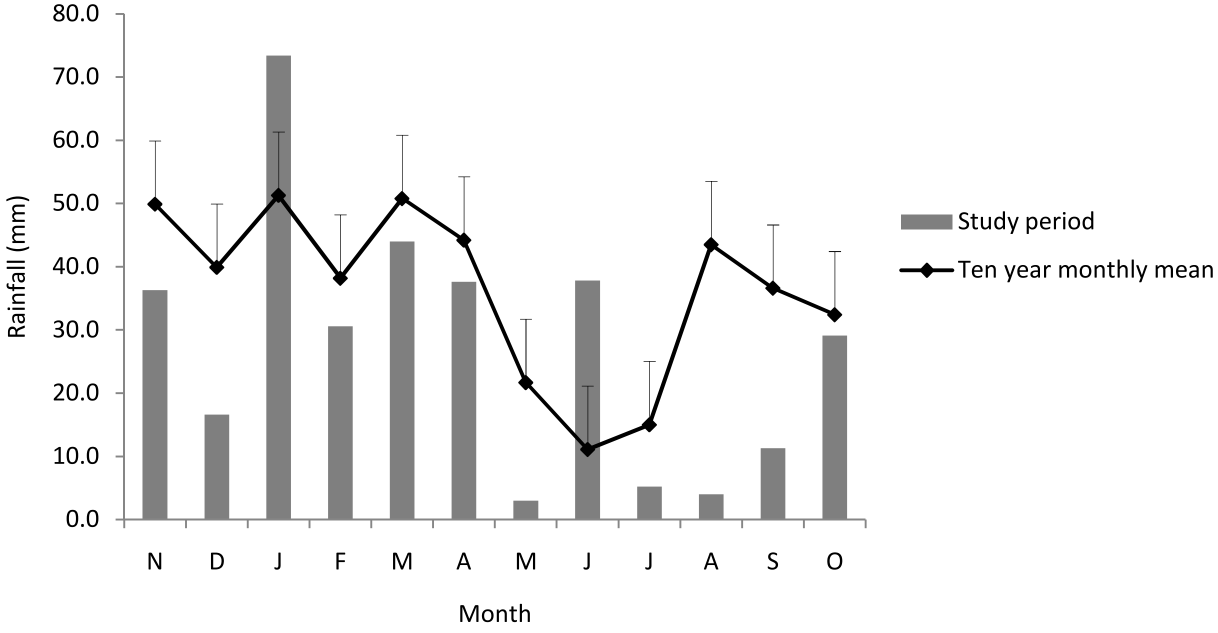

Figure 2.4: The monthly rainfall for the Great Fish River Reserve during the study period (2009-2010) in relation to the mean (± SD) monthly rainfall for the ten-year period 1999-2008.

Topography and geology

The topography of the reserve is dominated by steep valleys and gorges in the vicinity of the river in the east while the western and central sections are characterised by open plains and undulating terrain (Cent & Fike 2003). The reserve is located in the Great Fish River basin (Nicol 1988).

The geology of the Eastern Cape is comprised of the Uitenhage, Karoo and Cape supergroups (SACS 1980; Nicol 1988; Rust 1998). The soils range from deep solonetic soils originating from dolerites of the Beaufort group through to the sandy clays and lithosols of the Cape supergroup and the Dwyka and Ecca shale formations of the Karoo supergroup (Johnson *et al.* 1996; Low & Rebelo 1996). The geology of the study site is dominated by the Fort Brown formation of the Ecca group consisting of a succession of rhythmically bedded dark grey shale units with isolated intercalated sandstones (SACS 1980; Rust 1998). The Koonap formation of the Beaufort group consisting of sandstone, limestone and mudstone occurs in the vicinity of the Great Fish River (SACS 1980). Dolerite dykes cut through these formations and can be seen along the river (Brown 2008). The banks adjacent to the river are dominated by sandy-clay soils.

Vegetation

The vegetation of the Eastern Cape is described by Lubke *et al.* (1988) as being extremely diverse and phytogeographically complex. According to Rutherford *et al.* (2006a), the Eastern Cape Province has the highest number of biomes in South Africa, including all but the Desert Biome.

According to Low & Rebelo (1996), the majority of the vegetation of Great Fish comprises thicket. This is further divided into three vegetation types including Valley thicket, Xeric succulent thicket and Spekboom succulent thicket. However, numerous independent studies have been conducted in the Thicket Biome of the Eastern Cape, resulting in the vegetation of this area being interpreted in many ways (Bissett 2007). Succulent thicket is better known as Valley Bushveld according to the terminology used by Acocks (1988). This veld type is found in the valleys of the numerous rivers in the Eastern Cape that drain into the Indian Ocean. However, in the case of the Great Fish and Sundays River valleys which have wide, flat, dry bottoms, the genuine Valley Bushveld usually only occurs on the steep, less arid northern sides of these valleys. The vegetation of the lower Great Fish River valley was termed Fish River Scrub by Acocks (1988) and is an extremely dense, semi-succulent, thorny scrub, about 2m high.

The vegetation of Great Fish has most recently been described as part of the Savanna and Albany Thicket Biomes (Hoare *et al.* 2006; Rutherford *et al.* 2006b). According to Rutherford *et al.* (2006b), the sub-escarpment Savanna vegetation unit Bhisho Thornveld, is present in the extreme northern section of the reserve. This open vegetation type occurs on undulating to moderately steep slopes and in drainage lines, and is characterised by small trees of *Acacia karroo*. The under storey comprises short to medium, dense grasses usually dominated by *Themeda triandra* when in good condition (Rutherford *et al.* 2006b). The vegetation of the balance of the reserve is dominated by the Great Fish Thicket vegetation unit (Hoare *et al.* 2006). This vegetation supports a small, medium and tall type where woody trees, shrubs and a succulent component with many spinescent shrubs are well developed (Hoare *et al.* 2006). *Portulacaria afra* is locally dominant, but is replaced by *Euphorbia bothae* with increasing aridity. As the southern-facing slopes are wetter and in the riparian zone, *P. afra* is replaced by woody elements and tall emergent *E. tetragona* and *E. triangularis*. There is distinct clumping in this vegetation type which is linked to zoogenic mounds forming islands of concentrated nutrients and moisture (Hoare *et al.* 2006). These have richer, deeper soils and are often occupied by long-lived woody shrubs and trees such as *Pappea capensis* and *Boscia oleoides*. Great Fish Noorsveld occurs only in the south-western section of Great Fish (Hoare *et al.* 2006). This vegetation unit is prevalent on plateaus and mildly sloping ridges supporting low to medium height succulent thicket dominated by *E. bothae* and other *Euphorbia* species (Hoare *et al.* 2006).

This classification was further sub-divided by Trollope *et al.* (2006) who recognised 10 different vegetation types including short *Euphorbia* thicket, tall *Euphorbia* thicket, medium *Portulacaria* thicket, bushclump karroid thicket, riverine *Acacia* thicket, bushclump Savanna, *Acacia* savanna, grassland, karroid *Cynodon* shrubland and dry forest (Figure 2.5).

The short *Euphorbia* thicket vegetation type is characterised by short growing stands of *E. bothae* shrubs that may be replaced by *Euphorbia corulescens* in some areas, with sparse patches of *P. afra* (Trollope *et al.* 2006). Other woody species include *P. capensis* and *Euclea undulata*. This vegetation type grows on shallow soils overlying Ecca shales (Bissett 2007).

Tall *Euphorbia* thicket is dominated by tall-growing, continuous stands of *E. tetragona* and *E. triangularis* usually found on steep slopes (Trollope *et al.* 2006). The under storey is dominated by the grasses *Panicum deustem* and *Panicum maximum* whilst other tree species include *Maytenus undata*, *Elaeodendron zeyheri* and *Cussonia spicata* (Bissett 2007).

Medium *Portulacaria* thicket is the dominant vegetation type in the southern and eastern sections of the AVKR. It comprises dense stands of *P. afra* interspersed with *P. capensis*. The under storey is mostly bare in the western areas but comprises an herbaceous layer of *T. triandra, Digitria eriantha* and *P. maximum* grasses in the east (Trollope *et al.* 2006).

The bushclump karroid thicket vegetation type is found on the sandy/clay colluvial slopes bordering the alluvial plains of the Great Fish River (Bissett 2007). It is characteristic by *Rhus* *refracta*, *R. longispina*, *E. undulata*, *Gymnosporia polyacantha* tree species and *Scutia myrtina* bushclumps. The karroid herbaceous layer is characterized by *Setaria neglecta* and *D. eriantha*. The landscape is characterized by clumps of trees interspersed with patches of grass and *Pentzia incana* as the dominant karroid shrub (Trollope *et al.* 2006).

The riverine *Acacia* thicket vegetation type is characterised by dense *A. karroo* tree communities growing on the alluvial soils bordering the Great Fish River and its tributaries. Other characteristic tree species include *R. lancea* and *Combretum caffrum* whilst the herbaceous layer is dominated by *P. maximum.*

The bushclump savanna vegetation type differs climatically from bushclump karroid thicket in that it occurs at higher altitude and thus it is found in a cooler wetter environment (Bissett 2007). It is characterised by dense thornveld dominated by the following tree species: *C. spicata*, *S. myrtina*, *Fluggea verucossa*, *Psydrax ovata*, *Olea europaea* and *Ptaeroxylon obliquum*. Characteristic grass species include *D. eriantha*, *S. neglecta* and *Eustachys paspaloides*. The landscape is characterised by clumps interspersed with patches of grass. *Chrysocoma ciliata* is the dominant karroid shrub as opposed to *P. incana* in bushclump karroid thicket (Trollope *et al.* 2006; Bissett 2007).

Acacia savanna vegetation is characterised by open thornveld dominated by *A. karroo* trees and shrubs (Trollope *et al.* 2006). The under storey comprises short to medium, dense grasses usually dominated by *T. triandra* when in good condition (Rutherford *et al.* 2006b).

Grassland vegetation is characterised by open areas dominated by *T. triandra, Sporobolus fimbriatus* and *D. eriantha* (Trollope *et al.* 2006). This vegetation type is usually found on the top of ridges in the reserve.

Karroid *Cynodon* shrubland is characterised by short growing karoo shrublets and a stoloniferous grass cover of *Cynodon dactylon* (Trollope *et al.* 2006). It is recognised by large open areas dotted throughout with trees and bushes. Dominant tree species include *P. capensis* and *R. refracta* (Bissett 2007). The dominant characteristic of this vegetation type is the karroid herbaceous layer, made up exclusively of *P. incana*. The grass cover is usually sparse and includes characteristic species such as *D. eriantha* and *C. dactylon.*

Dry forest is the transition vegetation type between afromontane forest and valley thicket and is found in the steep valleys and gorges of the reserve (Bissett 2007). The trees are generally between 5 and 10 m tall and there is a distinct shrub and herbaceous layer. The tall growing tree species characterising this vegetation type include *Schotia latifolia, Hippobromus pauciflora, Viperus undulata* and *Harpephylum caffrum* (Trollope *et al.* 2006). Shrubs and climbers are common and include *Gymnosporia heterophylla, S. myrtina, Carissa bispinosa* and *Rhoicissus tridentate* (Bissett 2007). The under storey is dominated by the grasses *P. deustem* and *P. maximum*.

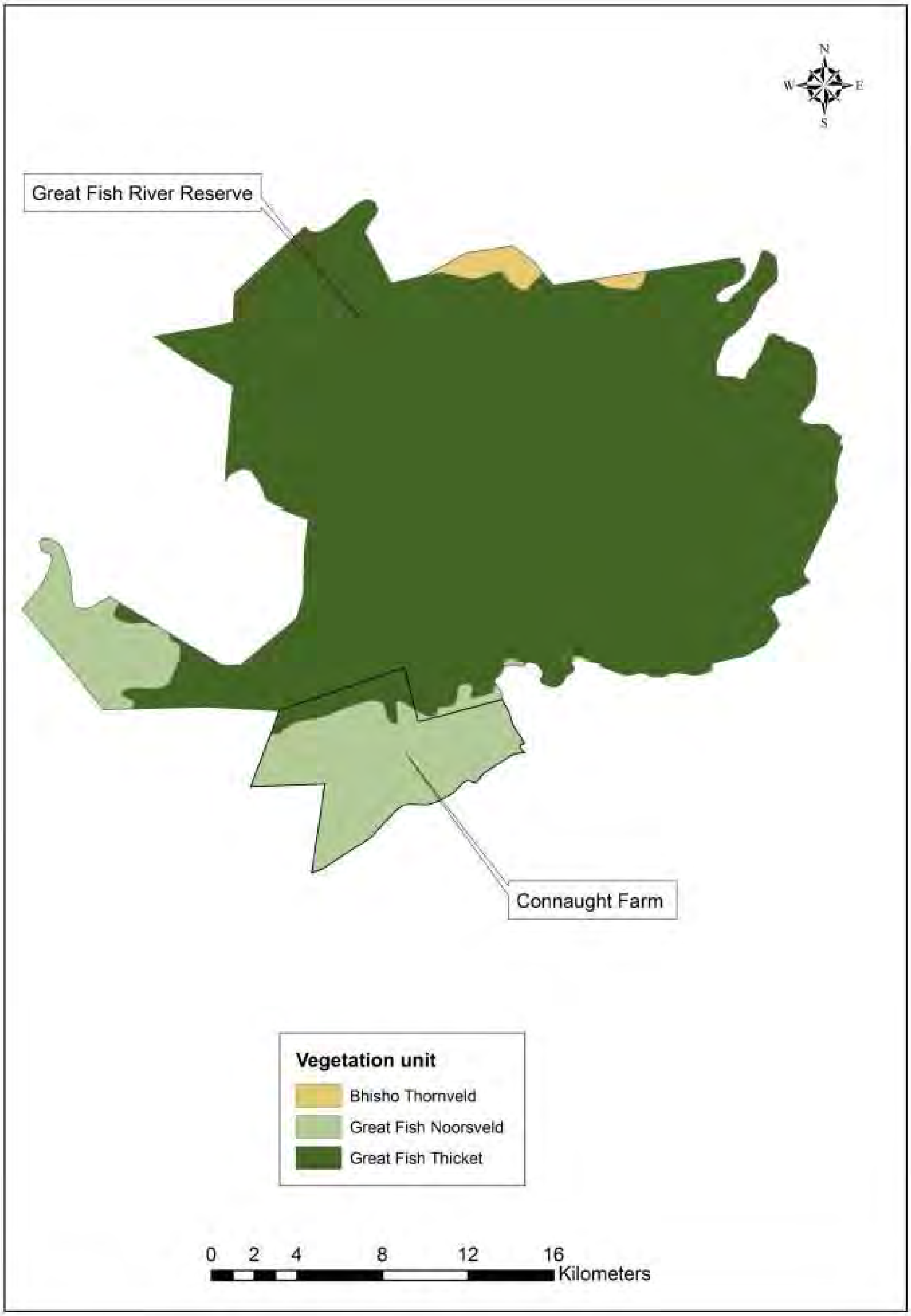

Figure 2.5: The distribution of the vegetation units on the Great Fish River Reserve and Connaught farm according to Mucina & Rutherford (2006) (ArcGIS 9; map units: decimal degrees; not projected).

2.4 CONNAUGHT FARM

Site description and history

Connaught is located 5 km west of Committee's Drift and is on the southern boundary of Great Fish (Figure 2.1). The site is comprised of four farms, *viz*. Connaught, Leinster, Athlone and a portion of Glen Boyd totalling an area of 3 700 ha. There are no natural permanent water sources; however, water is artificially available in all the camps.

The Webber family began small-stock farming in 1963 on their current farm. The previous land owners kept livestock (dorper sheep and cattle) but farmed on a considerably smaller scale. The farming operation was rapidly grown to a commercial scale and has remained this way since the 1970's. A combination of dorper sheep and Angora goats are currently farmed, totalling approximately 1 250 head of stock (600 Dorper ewes, 650 Angora ewes). Initially, there were no fenced camps and stock were herded and grazed on different parts of the farm before returning to a kraal (a local term defining an enclosure for livestock usually using a combination of mud-packed walls and thorny bushes) in the vicinity of the homestead. Fencing was introduced by the mid 1970s' and camps were enclosed with wire netting (80 cm high) and four to six strands of steel wire.

The tick-borne disease heartwater, caused by the bacterium *Cowdria ruminantium*, is accountable for significant stock losses (approximately 75 head of stock annually) on this farm (Webber *pers. comm.*). However, with the development of inoculations, vaccines and dipping solutions the problem has been greatly reduced. In addition, Connaught lost approximately 150 head of stock annually due to predation prior to 2004. The primary predators responsible for stock loss on the Webber's farm are black-backed jackals and caracals, and occasional anecdotal accounts of leopards in the past. Between one and three adult sheep were lost per week annually and up to seven lambs or kids were lost per week during the lambing and kidding seasons respectively. This translated to an approximate loss of 100 000 ZAR per annum.

In order to reduce stock losses, a variety of predator eradication methods have been employed. These include hunting with dogs, gin-traps, box-traps, cyanide guns and poison-baiting. This was associated with fairly intensive fence management and maintenance. Fences are patrolled on a weekly basis ensuring holes are filled in and damage to the fence structure repaired. Prior to 2004, black-backed jackals and caracals were killed in equal numbers; the farmer removing at least 25 individuals of each species per year. However, these two species were not the only problem animals in the area. The introduction of common warthog *Phacochoerus africanus* into neighbouring AVKR in 1983 led to their rapid colonisation of the reserve and subsequent spreading onto adjoining properties. The warthogs burrow beneath the fences creating a thoroughfare for other animals such as the black-backed jackals into the fenced camps. This exacerbates the stock loss problem as fence lines are no longer a reliable barrier and black-backed jackal are able to move between camps more easily (Webber *pers. comm.*).

The continued losses experienced by the Webbers drove them to introduce electrified fencing. A single electrified strand 10 cm high and 10 cm away from the fence was erected on either side of each fence line. A single electrified strand was further erected on top of the fence. The strand along the bottom prevented animals from burrowing beneath the fence and the strand on top reduced movement over the fence. Stock loss due to predation was reduced by 50 %

within a year (Webber *pers. comm.*). The Webbers now destroy 80 % fewer black-backed jackals per year; only killing an average of five per annum.

Topography and geology

The topography of the farm is dominated by steep valleys and gorges in the north which gradually ease into a valley of gently undulating terrain in the south. The altitude of the farm ranges from approximately 400 m above sea level on the ridge to 170 m above sea level on the valley floor. The geology of the farm is very similar to the AVKR being dominated by shales of the Ecca group.

Vegetation

The vegetation of the farm is similar to that of Great Fish (Figure 2.5). Short *Euphorbia* thicket and bushclump karroid thicket are found in the south of the farm whilst tall *Euphorbia* thicket characterises the vegetation of the slopes in the north of the farm. Medium *Portulacaria* thicket dominates the vegetation of the gentle valleys and undulating terrain in the south and forms the dominant vegetation type on the farm. Dry forest is present in small patches in the extreme north of the farm on the southern aspects of the steep valleys. Bissett (2007) described the vegetation of Kwandwe Private Game Reserve approximately 1 km to the west of Great Fish and defined another vegetation type, *viz.* the *Euphorbia Portulacaria* mosaic which is also present on the farm.

2.5 SHAMWARI PRIVATE GAME RESERVE

Site description and history

Shamwari is located within the Albany and Alexandria districts and is situated between Alicedale in the north and the N2 national road in the south (Figure 2.1; Parker 2004; Rapson 2004). The reserve was founded in 1993 and is approximately 23 000 ha in size. Three secondary roads traverse the length of the reserve from east to west. The reserve is currently surrounded by privately owned farmland and other conservation land. The reserve's major water source is the semi-perennial Bushman's River which flows through the southern section of the reserve for 27.6 km (Figure 2.6). There are numerous other small dams, pans, and boreholes originally created for irrigation purposes that are also utilised by game as alternative water sources (Parker 2004; Rapson 2004). As is prescribed for game reserves in South Africa that are reintroducing dangerous species, the perimeter of the reserve is fenced with electrified game fencing.

Before the reserve was established the area was dominated by extensive farming of merino sheep and cattle *Bos primigenius* for both beef and dairy. Pastures were planted to supplement livestock grazing and popular crops grown included; wheat *Triticum* spp., oats *Avena sativa*, chicory *Cichorium intybus* and pineapples *Ananas comosus*. The cropping on the reserve before it was formed occurred mostly along the Bushman's River in the southern sector. Many of these areas were cleared of the naturally occurring *Acacia* thicket vegetation, often up to the water's edge, and have been lying fallow since the inception of the reserve. They are in various successional stages of reverting to the original vegetation.

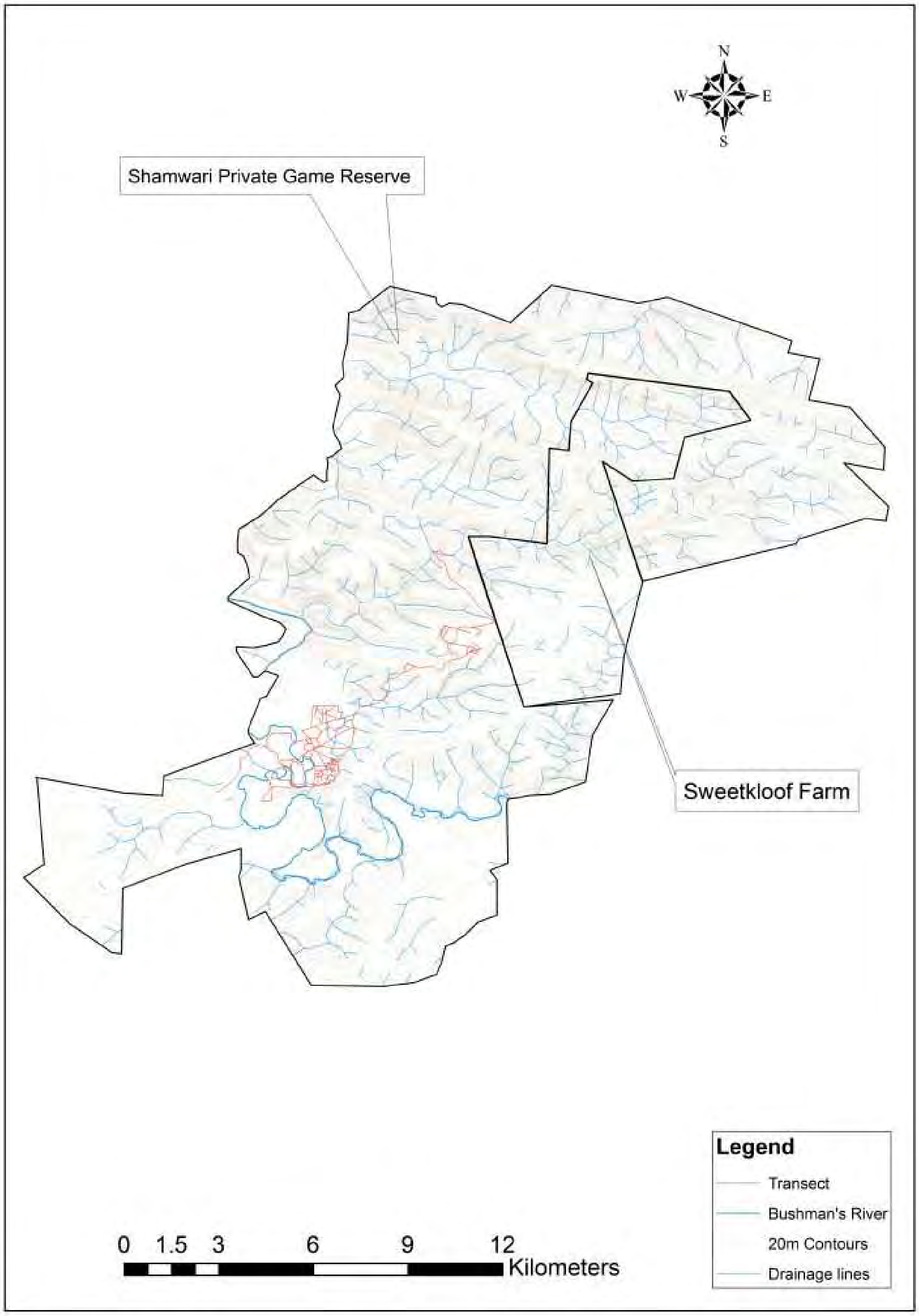

Figure 2.6: The topography and drainage patterns of Shamwari Private Game Reserve and Sweetkloof farm, and the road transect at Shamwari Private Game Reserve (ArcGIS 9; map units: decimal degrees; not projected).

Climate

According to the Köppen classification system, the climate of the study area is described as warm and temperate with all months experiencing temperatures between 10 °C and 22 °C and at least 60 mm of rainfall per month (Schulze 1947; Kopke 1988). Frost can occur on cold winter nights, particularly in the low-lying areas (Rapson 2004).

Temperature data were not available for the reserve, so data for Addo (≈ 40 km south-west of Shamwari) were used (Roux 2006). The overall mean maximum and minimum temperatures during the study period were 27.3 °C and 11.4 °C respectively. The mean maximum temperature for summer during the study period was 30.4 °C whilst the mean minimum temperature during winter dropped to 6.0 °C. The warmest (32.1 °C) and coldest (5.6 °C) mean temperatures recorded during the study period occurred in February and July respectively (Figure 2.7). The mean monthly temperatures recorded during the study period (2009-2010) differed very little from the ten-year monthly means (Figure 2.7).

Rainfall events may occur throughout the year with bimodal maxima usually occurring during the equinox periods (Kopke 1988; Burroughs & Palmer 1992; Stone *et al.* 1998). The topography of the reserve plays a significant role in the seasonal distribution of this rainfall where the reserve experiences considerably more rainfall in the north-east compared with the southern sector (O'Brien 2004). Shamwari receives approximately 550 mm of rainfall per annum (Low & Rebello 1996). The total annual precipitation during the study period was 397 mm which is approximately 110 mm lower than the annual ten year mean (± SD) of 510 ± 145.7 mm (Figure 2.8).

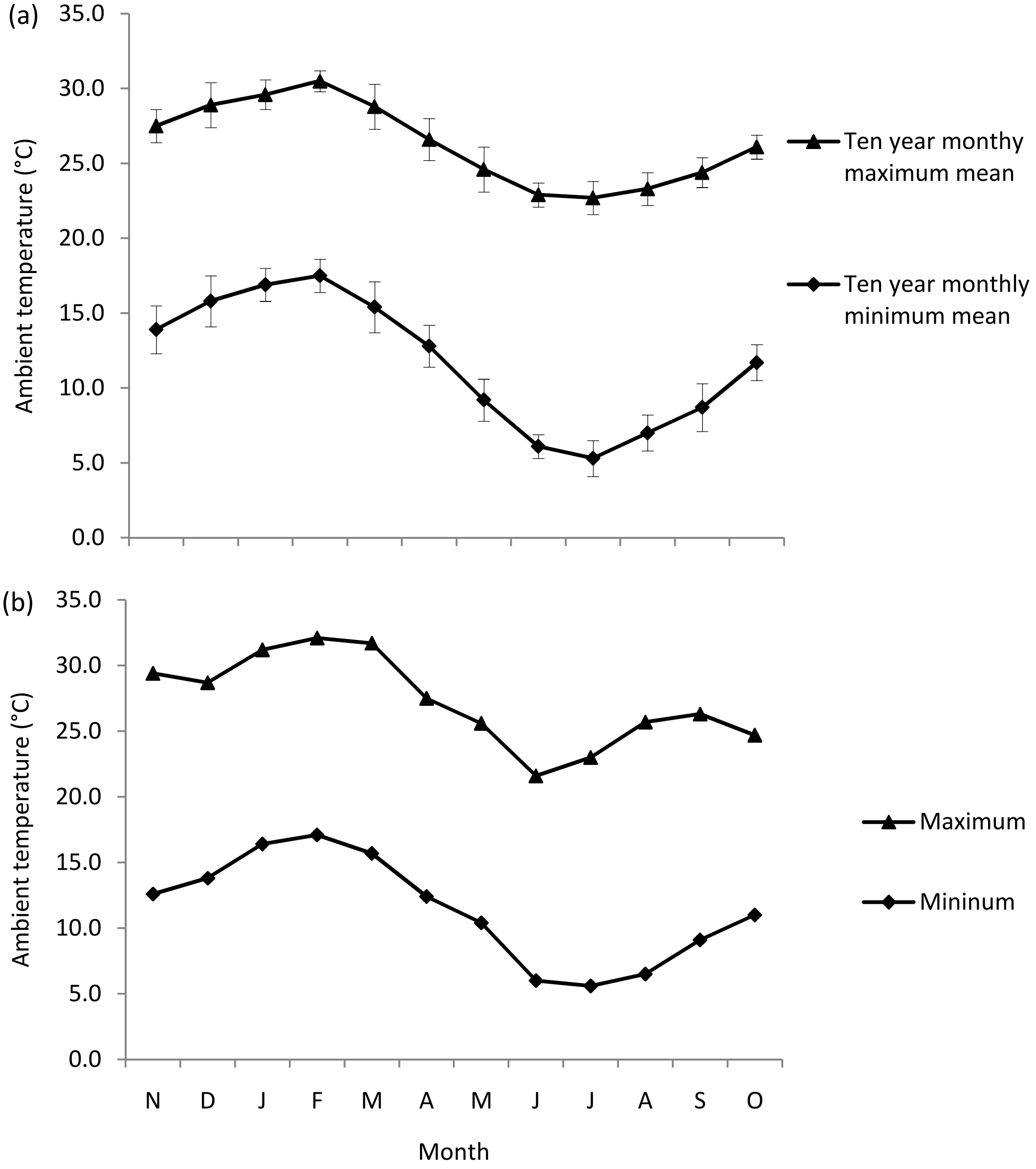

Figure 2.7: The mean monthly maximum and minimum temperatures for Shamwari Private Game Reserve for (a) the ten-year period 1999-2008 and (b) the study period 2009-2010.

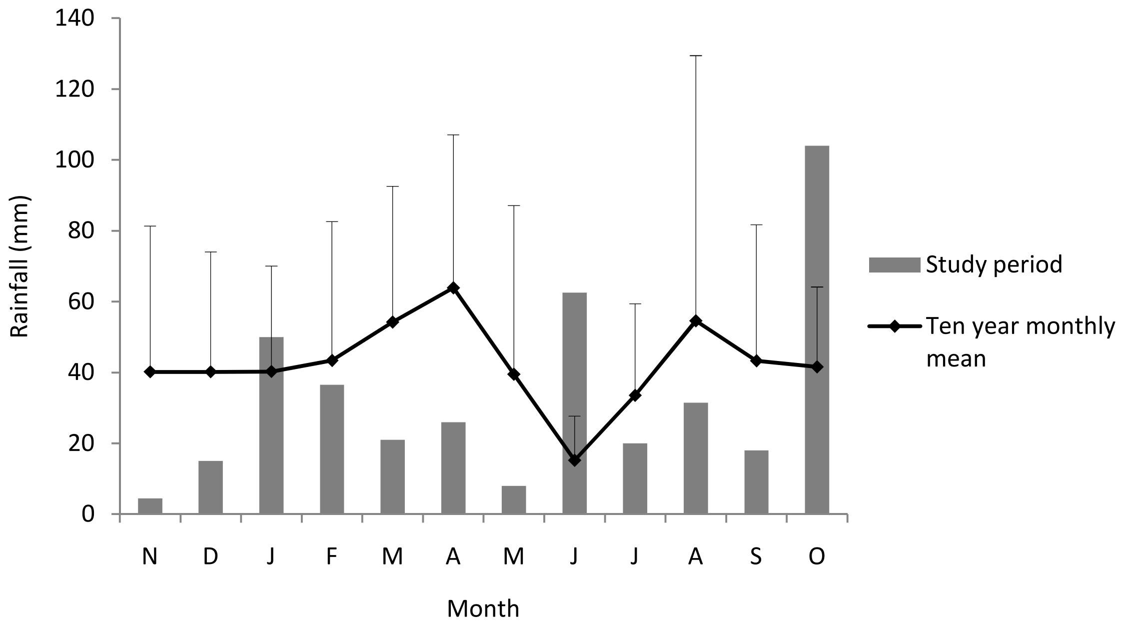

Figure 2.8: The monthly rainfall for Shamwari Private Game Reserve during the study period (2009-2010) in relation to the mean monthly rainfall for the ten-year period 1999-2008.

Topography and geology

The topography of the reserve varies considerably from gently undulating hills in the south to deep valleys and gorges in the north. The elevation gradient of the reserve ranges from 196 m above sea level in the south to 628 m above sea level in the north. The reserve is situated in the Bushman’s / Kowie River basin (Nicol 1988).

The geology of the reserve is quite complex as it is located at the meeting point between the Karoo and Cape supergroups, and the younger deposits of the Algoa group (Rust 1998). The dominant geological formations are the Bokkeveld shale series and the Witteberg quartzites of the Cape supergroup, the Karoo sandstones of the Karoo supergroup, and the Sundays River formation (O'Brien 2004). Quartzite ridges running in an east-west direction dominate the central and northern parts of the reserve and divide it into distinct geomorphological zones separated from one another by each ridgeline (Burroughs & Palmer 1992). The Sundays River formation dominates the southern section of the reserve comprising shallow soils underlain by calcrete. Four major substrata are found; *viz.* shale, sandstone, quartzite and calcrete. In addition, deeper alluvial soils are found on the lower lying areas (O'Brien 2004).

Vegetation

The vegetation of Shamwari is classified under the Albany Thicket, Savanna and Fynbos biomes (Hoare *et al.* 2006; Rebelo *et al.* 2006; Rutherford *et al.* 2006b). This includes the dominant vegetation unit, Kowie thicket, occurring over most of the reserve, Bhisho thornveld, occurring in the central areas and a small portion of Albany coastal belt in the extreme south-west of the reserve. The northern and north-eastern areas of the reserve are mostly dominated by Suurberg quartzite Fynbos and smaller patches of Suurberg shale Fynbos.

However, the vegetation was further sub-divided by O'Brien (2004) into fourteen different types including afromontane forest, succulent subtropical thicket, woody subtropical thicket, bontveld, bushclump savanna, riverine bush, primary *Acacia* thicket, secondary *Acacia* thicket, grassy fynbos, calcrete fynbos, montane grassland, lowland grassland, and cleared and cultivated lands (Figure 2.9).

The afromontane forest occurs in particularly deep valleys, ravines or steep gullies within the subtropical thicket where the moisture is highest. This vegetation type is analogous to the dry forest of Great Fish except it is structurally more developed. It occupies a patchy distribution predominantly in the northern section of the reserve. It is structurally dominated by tall (30 – 40 m) trees with distinct strata of emergent and canopy trees (O'Brien 2004). Characteristic tree species include *Podocarpus falcatus, S. latifolia, H. caffrum* and *H. pauciflorus.* According to Low & Rebelo (2006), dominant shrub and herb layer species include *G. heterophylla, S. myrtina* and *R. tridentate*.

Succulent subtropical thicket is an important, dominant vegetation type generally occurring on shale and sandstone derived substrata on sloping northern aspect ground. This vegetation type, as well as woody subtropical thicket, which is generally found on the cooler southern aspect slopes is analogous in a broad sense to a number of the thicket vegetation subunits of Great Fish including bushclump karroid thicket, medium *Portulacaria* thicket and *Euphorbia* thicket. Characteristic species of this vegetation type include *P. afra*, *Crassula muscosa* and *C. perforata*. Other associated species include *Schotia afra, C. bispinosa, P. capensis, E. undulata, Sideroxylon inerme* and *Aloe* spp. (O'Brien 2004). Succulents including *P. afra* and *Crassula* spp. are absent in the cooler, more moist areas where woody subtropical thicket occurs and forms the primary aspect separating it from succulent subtropical thicket. Characteristic species of this vegetation type include *E. triangularis, O. europaea, P. obliquum, Mystroxylon aethiopicum, S. myrtina* and *Plumbago auriculata* (O'Brien 2004).

The bontveld vegetation is restricted to the flat and moderately sloping calcrete soils in the south of the reserve and is not found on Great Fish. The vegetation consists of bushclumps interspersed with grass and/or shrubs of Karoo affinity (Parker 2004). The bushclumps typically comprise several *Rhus* spp., *Canthium inerme*, *Zanthoxylem capense*, *S. myrtina* and *Grewia occidentalis* (O'Brien, 2004). Characteristic climbers include *R. tridentata* and *Secamone alpinii*. The dominant perennial grasses include *T. triandra, Eragrostis curvula, Brachiaria serrata, D. eriantha, Sporobolus africanus* and *S. fimbriatus* (O'Brien 2004).

Bushclump savanna has the same basic structure as bontveld and is analogous to the bushclump savanna found Great Fish. This vegetation type is patchily distributed across the reserve and has the same vegetation composition as bontveld except lower relative abundances of *P. capensis* and higher relative abundances of *O. europaea* and *C. spicata*. It differs from bontveld in that it occurs on deep soils without a calcrete substratum (O'Brien 2004).

The riverine bush (riverine thicket) is limited to the banks of the Bushman's river and certain temporary watercourses on the reserve. Primary and secondary *Acacia* thicket and this vegetation type are analogous to the riverine *Acacia* thicket of Great Fish. Characteristic species include *C. caffrum, Acacia caffra* and *Rhus macowanii* (O'Brien 2004). The primary *Acacia* thicket is generally found near watercourses on the low-lying flat land of the reserve in areas that were previously cleared for agriculture. It is characterised by two dominant woody species *R. longispina* and *A. karroo*. The principal difference between primary and secondary *Acacia* thicket is the relative abundance of the above-mentioned species. Other characteristic species include *Azima tetracantha, E. undulata, G. heterophylla* and *Cadaba aphylla* (O'Brien 2004). Secondary *Acacia* thicket occurs where primary *Acacia* thicket has been disturbed through vegetation clearing, overgrazing or mismanagement. *Acacia karroo* dominates these thickets with secondary species including *R. longispina, C. aphylla* and *A. tetracantha* (O'Brien 2004; Parker 2004).

The grassy fynbos vegetation type occupies a very small distribution on the quartzite ridges in the northern part of the reserve. The complex communities are rich in a mixture of grasses, woody shrubs and small-leaved fynbos elements. Characteristic species of this vegetation type include *Leucadendron salignum*, *Passerina vulgaris*, *Aspalathus chortophila* and *Metalasia muricata*. The grass component includes *Pentachistis pallida*, *Heteropogon contortus* and *T. triandra* (O'Brien 2004; Parker 2004).

The calcrete fynbos is limited to a very small area in the north of the reserve. However, the presence of the vulnerable characteristic species *Syncarpha recurvata* warrants its inclusion as a vegetation unit. This vegetation type occurs on a calcrete substratum at a lower elevation than grassy fynbos and experiences a lower annual rainfall (O'Brien 2004).

The montane grassland is found in the central and northern sections of the reserve on a sandstone substratum. Lowland grassland and this vegetation type are analogous to the grassland vegetation type of Great Fish. It only occurs above the subtropical thicket fringe on the quartzite ridges at an altitude greater than 400 m above sea level. Characteristic species include *T. triandra*, *H. contortus*, *E. curvula*, *B. serriata* and *S. fimbritaus*. However, these areas are vulnerable to invasion by woody species such as *Elytropappus rhinocerotis*, *Pteronia incana*, *Rhus undulata* and *Selago corymbosa* in the absence of bulk grazers (O'Brien 2004; Parker 2004). Lowland grassland is only found in the south of the reserve at lower altitudes of 220 – 230 m above sea level. There is little variation in the topography of the area with very few woody species. Characteristic, dominant grass species include *T. triandra, E. curvula* and *D. eriantha* (O'Brien 2004).

Cleared lands are a disturbed habitat referring to areas where the original vegetation has previously been mechanically cleared to create grazing for livestock or used to cultivate crops. This vegetation occurs near the Bushman's River and is typical of the area surrounding homesteads and on cut-lines (*e.g*. fire breaks or similar area where bush has been cleared). These areas are in various successional stages of development; the species composition of each successional stage varying according to the original vegetation unit. However, *A. tetracantha* and various grass species are often prevalent in these areas (O'Brien 2004; Parker 2004).

Cultivated lands are old lands originally used for cultivating crops and are in various successional stages of development. These areas are mostly found along the Bushman's River. In the early stages of succession, they are dominated by ephemeral weedy species such as *Conyza scabrida, Galenia pubescens* and *Sasola kali,* certain succulents, *Drosanthemum floribundum* and *Mesembryanthemum aitonis* and grasses such as *Cynodon incompletus* and *Tragus racsmosus*. In the later stages of development they are characterised by species representing sub-climax grassland including *C. dactylon, S. africanus* and *Eragrostis plana* (O'Brien 2004; Parker 2004).

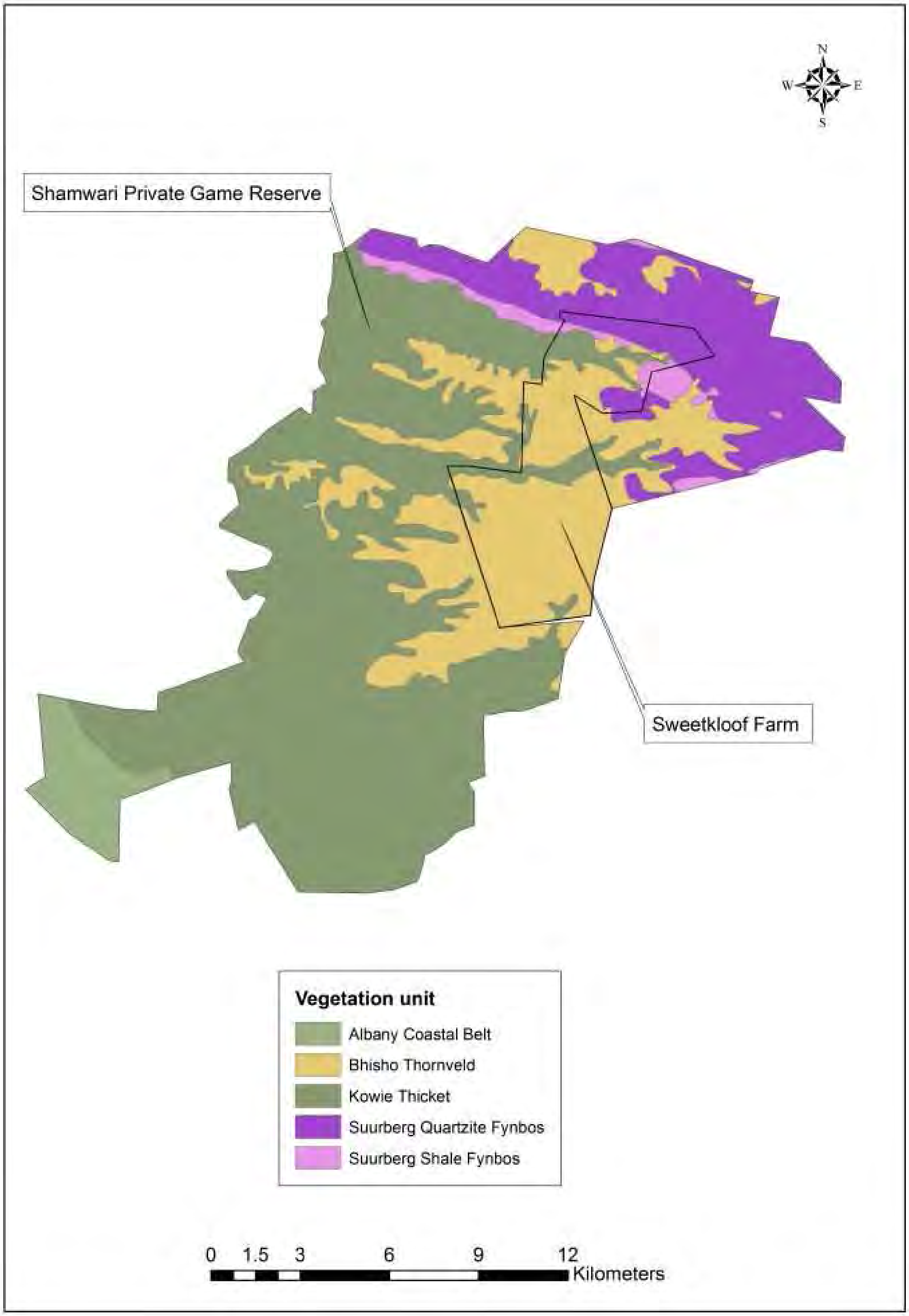

Figure 2.9: The distribution of the vegetation units on Shamwari Private Game Reserve and Sweetkloof farm according to Mucina & Rutherford (2006) (ArcGIS 9; map units: decimal degrees; not projected).

2.6 SWEETKLOOF FARM

Site description and history

Sweetkloof is situated 47 km west of Grahamstown on the eastern boundary of Shamwari (Figure 2.1). The land was bought by the family in the early 1800's and David Berrington is the sixth generation owner of the farms currently named Sweetkloof and Settlersvlei. The farm is 3 700 ha in size.

There are no naturally occurring permanent water sources on the farm, except ephemeral drainage line streams and depressions that may be temporarily filled after rainfall events (Figure 2.6). Artificially provided water in small dams and water troughs is permanently available across the farm. The farm is divided by two east-west secondary roads connected to the R342 regional road to Paterson and Alicedale respectively (Figure 2.1).

The Berrington family began small-stock farming in 1827 and by 1846 had as many as 7 000 merino sheep. The Berringtons currently own 3 700 Merino sheep comprising 3 200 adults and 500 lambs. Farming of Angora goats began in the 1980's, of which there are currently 370 individuals comprising 320 adults and 50 kids.

Before the Berringtons, local herdsmen traversed the area whilst moving subsistence herds of cattle between grazing areas. According to the Berrington's (*pers. comm.*), local wildlife was abundant and social hunts were commonplace. In the 1800's, there were no fences and livestock were herded freely between grazing areas. However, the losses experienced due to predation from wild carnivores drove the family to kraal their livestock at night in the vicinity of the homestead in the 1850's. What followed around the turn of the century were attempts to exclude wild carnivores through the construction of fenced camps with diamond-mesh predator-proof netting.

The primary source of stock loss remains predation (Berrington *pers. comm.*). Approximately two adult sheep are currently lost per week due to predation and up to 10 lambs or kids are lost per week during the lambing and kidding seasons respectively. There are typically three lambing seasons every two years, usually occurring every eight months. The first season normally begins in October. The primary predators responsible for stock predation are black-backed jackals and caracals, and occasionally, leopards. Total annual losses are estimated to be in the region of 200 individuals comprising approximately 50 % lambs or kids and 50 % adults (Berrington *pers. comm.*).

In order to reduce the losses due to predation, the Berringtons have employed a variety of methods including gin-traps, box-traps, a variety of poisons and the primary method of hunting dog packs.

The most recent method used by the Berrington's to reduce stock predation is that of sheep collars linked to a cellular phone. If the sheep are harassed, run and increase their heart rate a SMS (short-message-service) of warning is sent and the farmer can tend to the problem. According to Berrington (*pers. comm.*), the method is proving to be particularly useful.

Topography and geology

The topography and geology of the farm is very similar to that of neighbouring Shamwari. The northern and central sections are characterised by the continuation of the parallel east-west running ridges found in the reserve with steep valleys and gorges dominating the area. The contrasting topography of the southern section of the farm comprises gently undulating open terrain with a number of interspersed drainage lines.

The dominant geological formations on the farm are the Bokkeveld shale series and the Witteberg quartzites of the Cape supergroup and the Karoo sandstones of the Karoo supergroup. Four major substrata including shale, sandstone, quartzite and calcrete are found.

Vegetation

The vegetation of the farm is similar to that of Shamwari. Afromontane forest is found in small patches in the extreme north of the farm on the southern aspects of the steep valleys (Figure 2.9). Bushclump savanna and primary *Acacia* thicket dominate the vegetation of the southern areas combined with riverine bush in the many drainage lines. Grassy fynbos and montane grassland are found on the tops of the parallel quartzite ridges in the central and northern sections of the farm. Cleared and cultivated lands are most prevalent in the more open, undulating terrain in the south.

CHAPTER 3

THE DIET OF BLACK-BACKED JACKALS ON TWO CONTRASTING LAND-USE TYPES IN THE EASTERN CAPE PROVINCE, SOUTH AFRICA

3.1 INTRODUCTION

The diet of mammalian predators is affected by a range of factors including the abundance of the different prey items, the prey item's vulnerability, the prey item's ability to avoid predators, the nutritional demands of the predator and interspecific interactions with other predators (McFarland 1987; Mills & Gorman 1997; Perry & Pianka 1997; Krüger *et al.* 1999; Atkinson *et al.* 2002; Creel & Creel 2002; Mukherjee *et al.* 2004; Loveridge & Macdonald 2003; Pole *et al.* 2004; Radloff & du Toit 2004; Breuer 2005; Hayward & Kerley 2005; Garrott *et al.* 2007; van der Merwe *et al.* 2009). The vulnerability of a prey species is not only a species specific characteristic and will vary depending on the body condition of the animal (Owen-Smith & Mills 2008). The body condition of an individual is influenced by its age, reproductive status, health and environmental conditions such as drought (Gese *et al.* 1988; Capitani *et al.* 2004; Malo *et al.* 2004; Owen-Smith 2008; Owen-Smith & Mills 2008; Wegge *et al.* 2009).

In accordance with the optimal foraging theory (MacArthur & Pianka 1966), the diet of a generalist predator such as the black-backed jackal (Grafton 1965; Smithers 1983; Kaunda & Skinner 2003; Loveridge & Nel 2004; Skinner & Chimimba 2005; Klare *et al.* 2010) will vary as the relative abundance of one or more of a range of alternative prey species varies (Pyke *et al.*

1977). This dietary variation may be seasonal as seen in some mustelids (Ben-David *et al.* 1997; Martinoli *et al.* 2001; Begg *et al.* 2003), felids (Hayward & Kerley 2005; Hayward *et al.* 2006a; Canepuccia *et al.* 2007) and canids (Kruger *et al.* 1999; Aragona & Setz 2001; Atkinson *et al.* 2002). Alternatively, it may be due to habitat variation which influences the type of prey available and its abundance (Avenant & Nel 2002; Loveridge & Macdonald 2002; Manfredi *et al.* 2004; Mills *et al.* 2004). Moreover, this variation can be due to changes in land-use type where, for example, the diet of a species occurring in a protected conservation area may differ from the diet of conspecifics occurring on neighbouring farmland (Ott *et al.* 2007; Blaum *et al.* 2009b; Wallgren *et al.* 2009; Foster *et al.* 2010a).

Knowledge of the diet of predators and the source of this dietary variation is fundamental in understanding their foraging behaviour, population dynamics, habitat use and social organisation (Mills 1992; Manfredi *et al.* 2004). Furthermore, accurate descriptions of predator diet are mandatory for understanding the dynamics of predator-prey relationships, the structure of food webs and their trophic interactions (Schoener 1971; Paine 1980; Stephens & Krebs 1986; Pimm *et al.* 1991; Sih *et al.* 1998; Herbst & Mills 2010).

The black-backed jackal has been described as an opportunistic omnivore (Shortridge 1934; Grafton 1965; Smithers 1983; Sheldon 1992; Kingdon 1997; Mills & Hes 1997; Walton & Joly 2003; Loveridge & Nel 2004; Skinner & Chimimba 2005) feeding on whichever prey is in greatest abundance or most easily captured (Rowe-Rowe 1983; Skinner & Chimimba 2005). Similar to other jackal species (*C. adustus* and *C. aureus*), the dietary composition of the black-backed jackal is extremely broad and includes vertebrates, invertebrates, plant material, occasionally anthropogenic items (e.g. plastic, rubber) and inorganic items such as rocks, stones or pebbles (Shortridge 1934; Grafton 1965; Bothma 1971b; Rowe-Rowe 1975, 1976; Hall-Martin & Botha 1980; Stuart 1981; Rowe-Rowe 1983; Smithers 1983; Bothma *et al.* 1984; Avery *et al.* 1987; Hiscocks & Perrin 1987; Bussiahn 1997; Nel *et al.* 1997; Atkinson *et al.* 2002; Lanskzi & Heltai 2002; Kaunda & Skinner 2003; Loveridge & Macdonald 2003; Walton & Joly 2003; Loveridge & Nel 2004; Skinner & Chimimba 2005; Lanskzi *et al.* 2006; Jaeger *et al.* 2007; Do Linh San *et al.* 2009; Giannatos *et al.* 2009; Lanskzi *et al.* 2009; van der Merwe *et al.* 2009; Klare *et al.* 2010).

The vertebrate component of the diet consists of up to six different mammalian orders (Grafton 1965; Bothma 1971b; Stuart 1976; Rowe-Rowe 1983; Smithers 1983; Avery *et al.* 1987; Kingdon 1997; Nel *et al.* 1997; Loveridge & Macdonald 2003; Loveridge & Nel 2004; Walton & Joly 2003; Klare *et al.* 2010). Other vertebrates recorded include amphibians (Bothma 1971b; Skinner & Chimimba 2005), reptiles (e.g. snakes, lizards, tortoises; Rowe-Rowe 1983; Smithers 1983; Stuart 1987; Bussiahn 1997; Walton & Joly 2003; Skinner & Chimimba 2005; Do Linh San *et al.* 2009), birds and bird's eggs (Stuart 1976; Rowe-Rowe 1983; Smithers 1983; Hiscocks & Perrin 1987; Nel *et al.* 1997; Kaunda & Skinner 2003; Skinner & Chimimba 2005) and fish (Stuart 1976; Avery *et al.* 1987; Nel *et al.* 1997). Marine mammals such as the Antarctic fur seal *Arctocephalus pusillus* (Otariidae), dolphins (Cetacea, odontoceti) and baleen whales (Cetacea, mysteceti) have also been recorded in their diet along the Namibian coast (Hiscocks & Perrin 1987; Avery et al. 1987; Nel *et al.* 1997).

Black-backed jackals typically feed on small-sized prey ranging in size from insects and rodents (5 – 500 g), to small (≤ 15 kg) antelope species such as steenbok *Raphicerus campestris* (Skinner & Chimimba 2005) and the young of larger ungulate species *e.g.* Thomson's gazelle *Eudorcas thomsonii* (Wyman 1967). However, black-backed jackals are highly opportunistic and will hunt in cooperative groups when hunting larger or adult (~75 kg) ungulates (Skinner & Chimimba 2005) such as impala *Aepyceros melampus* (McKenzie 1990), springbok *Antidorcas marsupialis* (Moehlman 1978, Krofel 2007), Thomson's gazelle *Eudorcas thomsonii* (Wyman 1967; Sleicher 1973; Lamprecht 1978; Moehlman 1983), and Greater kudu *Tragelaphus strepsiceros* (Walton & Joly 2003).

Significantly, livestock including cattle, horses *Equus ferus*, sheep, goats, and pigs *Sus domestica* have also been reported in black-backed jackal diet (Grafton 1965; Bothma 1971b; Rowe-Rowe 1975, 1976; Stuart 1981; Rowe-Rowe 1983; Stuart 1987; Roberts 1986; Bussiahn 1997; Klare *et al.* 2010), with sheep being the most frequently consumed livestock species in South Africa (Grafton 1965). Peaks in the consumption of livestock occur during the lambing and kidding seasons (Bothma 1971b; Rowe-Rowe 1975, 1976; Lawson 1989). According to Rowe-Rowe (1975), the increase in predation can be explained by an increase in the abundance of easily obtainable prey during these periods. A second possible explanation is that despite lambing seasons being controlled by the farmer, they very often coincide with the breeding season of the black-backed jackal (July - October) when an increase in the demand for food to feed both adults and young occurs (Rowe-Rowe 1975).

Invertebrates consisting of molluscs (e.g. mussels, Stuart 1976; Hiscocks & Perrin 1987; Nel *et al.* 1997), crustaceans (e.g. crabs, Stuart 1976; Rowe-Rowe 1983; Nel *et al.* 1997), a range of arthropods including scorpions, myriapods and solifugids (Grafton 1965; Bothma 1971b; Stuart 1976; Skinner & Chimimba 2005) and insects (e.g. isoptera and coleoptera; Grafton 1965; Bothma 1971b; Stuart 1976; Hall-Martin & Botha 1980; Stuart 1981; Rowe-Rowe 1983; Smithers 1983; Nel *et al.* 1997; Skinner & Chimimba 2005; Do Linh San *et al.* 2009) may form a significant portion of black-backed jackal diet. Vegetation is a common constituent of the diet and may also include fruit and seeds (Stuart 1976; Smithers 1983; Skinner & Chimimba 2005; Do Linh San *et al.* 2009; van der Merwe *et al.* 2009). Plant material and sand, stones and pebbles are thought to be ingested to assist in the mechanical process of digestion and are also common in the stomachs of other canids (Smithers 1983).

Although black-backed jackals are capable hunters, facultative scavenging on carrion also forms a very important food source for the species (Smithers 1983; Walton & Joly 2003; Skinner & Chimimba 2005; Wilson & Wolkovich 2011). The prevalence of carrion in the diet may vary temporally and between regions (Grafton 1965; Bothma 1971b; Stuart 1976; Rowe-Rowe 1983; Smithers 1983; Avery *et al.* 1987; Stuart 1987; Bernard & Stuart 1992; Kingdon 1997; Mills & Hes 1997; Walton & Joly 2003; Skinner & Chimimba 2005; Wilson & Wolkovich 2011). In areas where large carnivores are present (e.g. lions, leopards, and spotted hyaenas) carrion is usually more freely available and occurs more frequently in their diet (Smithers 1983; van der Merwe *et al.* 2009). The temporal variation in the prevalence of carrion in jackal diet depends on the source of the carrion (Wilson & Wolkovich 2011). Winter seasons may result in the death of ungulates and therefore an increase in the amount of carrion being available (Bernard & Stuart 1992; Mduma 1999). Similarly, sheep carrion tends to be more available during lambing season due to early life stage complications (Rowe-Rowe 1975).

The relative occurrences of prey items in the diet of black-backed jackal vary primarily due to habitat type and season (Bussiahn 1997; Nel *et al.* 1997; Kaunda & Skinner 2003; Loveridge & Macdonald 2003; Skinner & Chimimba 2005; Do Linh San *et al.* 2009; Klare *et al.* 2010). For example, Klare *et al.* (2010) reported a seasonal increase in the prevalence of fruits in the diet during autumn and a decrease in the frequency of occurrence of ungulates in the diet during winter. Similarly, Kaunda & Skinner (2003) reported a seasonal increase in the incidence of mammals in the diet during winter and an increase in the prevalence of fruits in the diet during summer. The varied habitat types within which the black-backed jackal occurs further influences the diet of the species. For example, the dominant prey items of black-backed jackals occurring in the coastal desert of Namibia are seals, birds and fish (Avery *et al.* 1987; Hiscocks & Perrin 1987; Nel *et al.* 1997). This contrasts with the diet of black-backed jackals occurring in the montane grasslands of the Drakensberg, KwaZulu-Natal whose diet is dominated by small mammals and antelope carrion (Rowe-Rowe 1976; 1983).

Land-use type also influences the diet of black-backed jackals (Rowe-Rowe 1976; Bussiahn 1997). Rowe-Rowe (1976) studied the diet of black-backed jackal on reserves and farmlands in KwaZulu-Natal and concluded the diet of reserve jackal to be dominated (% volume) by antelope carrion, antelope and other mammals whilst farmland jackal diet was dominated by livestock carrion, sheep and antelope carrion.

The majority of research investigating the diet of black-backed jackal has been conducted on protected conservation areas such as game reserves (Bothma 1966; Stuart 1976; Stuart 1981; Rowe-Rowe 1983; Avery *et al.* 1987; Stuart 1987; Hiscocks & Perrin 1987; Nel *et al.* 1997; Kaunda & Skinner 2003; Loveridge & Macdonald 2003; Do Linh San *et al.* 2009; van der Merwe *et al.* 2009). Only three studies have described black-backed jackal diet on farmland (Rowe-Rowe 1975, 1976; Bussiahn 1997). Furthermore, only three studies describing black-backed jackal diet have been conducted in the Eastern Cape,South Africa. Hall-Martin & Botha (1980) analysed the contents of five black-backed jackal stomachs in the Addo Elephant National Park. However, the sample size was particularly small and did not allow for broad conclusions regarding their overall diet to be drawn. Moreover, there was insufficient data for a seasonal comparison to be made. Do Linh San *et al.* (2009) described the diet of black-backed jackal on the Andries Vosloo Kudu Reserve using scat analysis but this study was restricted to just one season, autumn. The unpublished research by Bussiahn (1997) was more extensive and described the dietary composition of black-backed jackals over 12 months on farmlands and on the Double Drift Game Reserve using stomach content analysis. Nevertheless, this research was limited to one region (like the two previous studies) preventing broad conclusions regarding the overall diet of black-backed jackal in the Eastern Cape from being drawn.

Thus, there is a clear need for a study describing the diet of black-backed jackal in the Eastern Cape over an entire seasonal cycle, with an adequate sample size, at more than one site and including two different land-use types (conservation and farmland). In this chapter I examine and describe the dietary composition of the black-backed jackal utilising scat analysis on two protected conservation areas and neighbouring farmland in the Eastern Cape Province, South Africa.

3.2 MATERIALS AND METHODS

The majority of early research on carnivore diet in South Africa examined stomach contents (Grafton 1965; Bothma 1966, 1971a, 1971b; Bothma *et al.* 1976; Stuart 1976; Trites & Joy 2005). Stuart (1976) suggested that the analysis of carnivore stomach contents is preferable to faecal analysis when describing diet due to the more accurate identification of food items before they are digested. Stomach content analysis does, however, have its own disadvantages, including the need to destroy large numbers of animals (Stuart 1976; Norbury & Sanson 1992). Mills (1996) then stated that faecal analysis was the most common method for analysing carnivore food habits for three reasons. The method has proved very useful for constructing a basic description of carnivore diet particularly in cases where other types of observations (e.g. direct observation) are not possible (Mills 1996; Klare *et al.* 2010). The method may also supplement observations, for example in the identification of small food items eaten but not identified during direct observations (Mills & Mills 1978; Mills 1996). The third reason is for inter- and intra-specific dietary comparisons (Mills & Mills 1978; Mills 1996). Faecal analysis does not require the animal to be destroyed and there are usually large numbers of scats available for study (Stuart 1976; Norbury & Sanson 1992; Ciucci *et al.* 1996; Marucco *et al.* 2008). The availability of large numbers of scats is important in faecal analyses in order to have sufficient sample representivity when describing the diet of the species (Trites & Joy 2005).

Small sample sizes may result in inaccurate conclusions and large sample sizes may result in the wasting of resources and unnecessary labour (Trites & Joy 2005).

Carnivore faecal analysis provides much information on dietary composition and allows for the feeding habits of the study animal to be continuously tracked (Stuart 1976; Putman 1984; Ciucci *et al.* 1996; Mills 1996; Foran *et al.* 1997; Kruger *et al.* 1999; Farrell *et al.* 2000; Marucco *et al.* 2008). Scat analysis does run the risk of not completely describing the diet of the study animal as certain food items may be completely absorbed by the animal's digestive tract or digested beyond recognition (e.g. soft-bodied insects and seedless fruits; Stuart 1976). However, the majority of the food items consumed by black-backed jackals show at least some trace in the scat e.g. hair, bone, cartilage, scales, feathers, seeds/nuts and plant material (Stuart 1976).

On the basis that the method of faecal analysis is non-invasive and non-destructive (Stuart 1976; Norbury & Sanson 1992; Ciucci *et al.* 1996; Mills 1996; Foran *et al.* 1997; Marucco *et al.* 2008), has been shown to accurately describe the diet of various canids (e.g. Stuart 1976; Rowe-Rowe 1983; Leopold & Krausman 1986; Avery *et al.* 1987; Hiscocks & Perrin 1987; Gese *et al.* 1988; Jedrzejewski & Jedrzejewska 1992; Sillero-Zubri & Gottelli 1995; Ciucci *et al.* 1996; Bussiahn 1997; Nel *et al.* 1997; Leckie *et al.* 1998; Kruger *et al.* 1999; Elmhagen *et al.* 2000; Arjo *et al.* 2002; Atkinson *et al.* 2002; Loveridge & Macdonald 2003; Capitani *et al.* 2004; Lanzski *et al.* 2006; Jaeger *et al.* 2007; Do Linh San *et al.* 2009; Giannatos *et al.* 2009; Liu *et al.* 2010), and covers a far broader spatial and temporal range in the diet than other techniques (Norbury &

Sanson 1992); it was considered an acceptable method for achieving the aims of this study (Stuart 1976; Kruger *et al.* 1999).

Scat collection

Scats were collected on a monthly basis between November 2009 and October 2010 from all four of the study sites. The number of scats collected each month per site was based upon the combination of scat abundance and previous research on black-backed jackal diet (Stuart 1976; Rowe-Rowe 1983; Avery *et al.* 1987; Hiscocks & Perrin 1987; Bussiahn 1997; Nel *et al.* 1997; Loveridge & Macdonald 2003; Do Linh San *et al.* 2009).

Before scat collection began, scat availability at all the study sites was investigated by driving a predetermined route. The concern of sample size and the associated question of how many faecal samples (scats) are sufficient to detect differences in diet at different temporal and/or spatial scales has long plagued the method (Trites & Joy 2005). Using Monte Carlo simulations of two computer generated scat populations with a maximum of 15 primary prey species, Trites & Joy (2005) determined that if the frequency of occurrence of the prey items are to decrease in a linear fashion, the minimum number of scats required to detect differences between the two populations was 23. However, when scats are collected in the field the frequency of occurrence of prey species tends to decline exponentially and not linearly (Ferreras & Macdonald 1999; Malo *et al.* 2004; Moleon & Gil-Sanchez 2003; Sinclair & Zeppelin 2002). Thus, a more realistic scenario indicated that at least 51 scats would be necessary to distinguish between two species populations consuming the same 15 primary prey species declining exponentially. However, previous research on black-backed jackal diet in the Eastern Cape indicates that collecting 30 scats is adequate (Do Linh San *et al.* 2009). In addition, this study identified 21 mammalian species in the overall diet; a number greater than the maximum used by Trites & Joy (2005). This was similar to Rowe-Rowe (1983) who identified 23 mammalian species in the diet of black-backed jackals in the KwaZulu-Natal Drakensberg. The number of prey species in the diet influences the number of scats that need to be collected and fewer scats are required to compare a more diverse (≥ 15 species) diet (Trites & Joy 2005). Thus, I aimed to collect 15 scats per month from each site.

Scats were collected along roadside transects at all sites (Great Fish – 19.7 km, Shamwari – 18.5 km, Connaught – 11.5 km, Sweetkloof – 10.8 km; Figure 2.2, 2.8). However, scats were also opportunistically collected whilst walking along major game/livestock paths at the two farmland sites. The roadside transect method greatly increases the chances of encountering scats, allows for greater sampling coverage of habitat types and has been extensively used in previous studies of predator diet (e.g. Corbett 1989; Ciucci *et al.* 1996; Jaeger *et al.* 2007; Kruger *et al.* 1999; Atkinson *et al.* 2002; Capitani *et al.* 2004; Glen & Dickman 2006; Lanzski *et al.* 2006; Marucco *et al.* 2008; Do Linh San *et al.* 2009; Giannatos *et al.* 2009; van der Merwe *et al.* 2009; Klare *et al.* 2010). Furthermore, roads also tend to be used by black-backed jackals as territorial boundaries (van de Merwe 1953a; Hayward & Hayward 2010) thus increasing the chance of encountering scats (Macdonald 1980). Traversing as many habitat types as possible has the advantage of allowing for the broadest dietary spectrum to be sampled at a particular site. Opportunistic collection on foot on the farmland sites was performed due to the shorter roadside transect distances covered and the need to sample a larger area in order to obtain the minimum number of scats required. The transects were also selected such that they traversed through a number of black-backed jackal territories.Scats were collected during the last seven days of every month (Glen & Dickman 2006). During the first month of collection (November 2009) exceptionally old scats identified by their pale colouration, lack of odour and a breakdown of the scat structure were removed from the respective transects. Collected scats were placed in Ziploc™ bags (17.7cm x 20.3cm) and the GPS location of the scat, the placement of the scat relative to the road/path (side or middle) and the substrate upon which the scat was found (shrub, grass or ground) were recorded. These scats were then placed in a freezer at approximately -20°C before being analysed (Ciucci *et al.* 2006; Lanzski *et al.* 2006; Giannatos *et al.* 2009).

Black-backed jackal scat identification was based on shape (cylindrical, tapered at one end), colour (varied from dark to pale brown), odour, the presence of associated field signs such as spoor, defecation site and by scat composition – the presence of fruits, seeds, insects and plant tissue etc. are characteristic of an omnivorous canid scat (Atkinson *et al.* 2002; Chame 2003; Breuer 2005; Glen & Dickman 2006; Jaeger *et al.* 2007; Do Linh San *et al.* 2009; Giannatos 2009; van der Merwe *et al.* 2009). If I was unsure of the species responsible for a scat it was not collected (Breuer 2005; Glen & Dickman 2006; Lanzski *et al.* 2006; Liu *et al.* 2010).

Overall diet analysis

The processing of faecal samples followed a standard procedure (e.g. Grafton 1965; Bothma 1971a; Bothma *et al.* 1976; Stuart 1976; Rowe-Rowe 1983; Bothma *et al.* 1984; Bussiahn 1997; Atkinson *et al.* 2002; Breuer 2005; Glen & Dickman 2006; Jaeger *et al.* 2007; Do Linh San *et al.* 2009; Giannatos *et al.* 2009; van der Merwe *et al.* 2009). All scats were placed in 500ml glass beakers filled with boiling water for a period of 24 hours to soften the material (Stuart 1976; Rowe-Rowe 1983; Hiscocks & Perrin 1987; Bowland & Bowland 1991; Breuer 2005; Lanzski *et al.* 2006; Jaeger *et al.* 2007; Do Linh San *et al.* 2009; Liu *et al.* 2010). The softened scats were then individually placed into white plastic sorting trays (50 cm x 35 cm x 4 cm) with approximately 750 ml water (Hiscocks & Perrin 1987).

The macroscopic presence/absence of the following prey categories was recorded: mammal hair, birds, reptiles, invertebrates, fruit / seeds, and vegetation (Grafton 1965; Bothma 1971a; Stuart 1976; Atkinson *et al.* 2002; Do Linh San *et al.* 2009; Giannatos *et al.* 2009; van der Merwe *et al.* 2009). Invertebrates (e.g. insects) found on the surface of the scats during collection were discarded (Jaeger *et al.* 2007). Any unidentified items in any of the respective categories were recorded as unknown (Stuart 1976; Liu *et al.* 2010). Mammalian hairs were removed using fine forceps and placed in sealable petri dishes. They were identified to species level through negative cuticle scale imprints and transverse sections (Williamson 1951; Perrin & Campbell 1980; Keogh 1983; Corbett 1989; Kruger *et al.* 1999; Bissett 2004; Glen & Dickman 2006; Do Linh San *et al.* 2009; Giannatos *et al.* 2009; van der Merwe *et al.* 2009; Klare *et al.* 2010). The fruit / seeds were identified to species level using the reference collection at the Selmar Schönland Herbarium, Albany Museum, Grahamstown, Eastern Cape. The invertebrates were identified to class level. Birds, reptiles and vegetation were not identified to finer taxonomic levels (Rowe-Rowe 1983; Atkinson *et al.* 2002; Do Linh San *et al.* 2009; Klare *et al.* 2010).

Hair analysis

All hairs were washed in warm water and left to dry for one hour before cuticle scale imprints were prepared in accordance with the method described by Keogh (1983). A 5% concentration of gelatine (Royal™) solution was mixed with boiling water in a 25ml beaker and was floated in a hot water bath to ensure the gelatine remained liquid (Bissett 2004). Glass slides were thinly coated with the gelatine solution and five hairs placed parallel to each other. The hairs were removed after 24 hours. The slides were observed under a Zeiss Primostar™ light microscope at medium power (x 400). Photographs were taken at the midpoint of the hair using a Canon Powershot™ A640 digital camera (10 megapixels) using an adaptor tube (52mm wide) connected to the microscope.

A reference collection of all possible mammalian prey species found at each of the four study sites was produced from hair samples collected from museum specimens (Amathole Museum, King William's Town, Eastern Cape Province) and prepared in the same way as those hairs removed from the scats. This reference collection, combined with those compiled by Keogh (1983, 1985) and Perrin & Campbell (1980), were utilised to identify all mammalian hairs to species level (Corbett 1989; Kruger *et al.* 1999; Atkinson *et al.* 2002; Bissett 2004; Capitani *et al.* 2004; Glen & Dickman 2006; Lanzski *et al.* 2006; Do Linh San *et al.* 2009; van der Merwe *et al.* 2009; Klare *et al.* 2010; Liu *et al.* 2010). In order to reduce observer subjectivity, every tenth hair of the entire sample was cross-examined by two other observers to maximise accuracy in identification (Capitani *et al.* 2004; Glen & Dickman 2006).

In order to determine the number of hairs necessary to establish sampling representivity for the mammal prey category, 20 scats were collected along the roadside transect at the Great Fish River Reserve at the end of May 2009. These scats were processed and all the hairs removed. Hairs were selected using a random number generator, photographed and identified to species level. Sample-based species accumulation curves were compiled through the analytically calculated S_{obs} (Mao Tau) (number of species expected) at the 95% confidence level (Colwell *et al.* 2004), the incidence-based coverage estimator (ICE) and the abundance-based coverage estimator (ACE) (Chazdon *et al.* 1998) using EstimateS V 7.5.2™ (Colwell 2009).

The richness estimates were considered representative when the observed sample-based species accumulation curve and the two estimators converged at the highest observed species richness (Longino *et al.* 2002). This method estimated that 35 hairs (removed from 20 scats) per month per site would be adequate (Figure 3.1). However, when the hair samples were grouped into five categories (5-10, 15-20, 25-30, 40-50 and 60-100 hairs), there was no significant difference ($p > 0.05$) in the cumulative number of species observed among the last four categories (Figure 3.2). Only the 5-10 hair categories had significantly fewer species than the other four categories (Figure 3.2; repeated measures ANOVA $F_{8,\ 8} = 9.49$, $p \leq 0.05$). Therefore, 30 hairs per month per site were deemed sufficient.

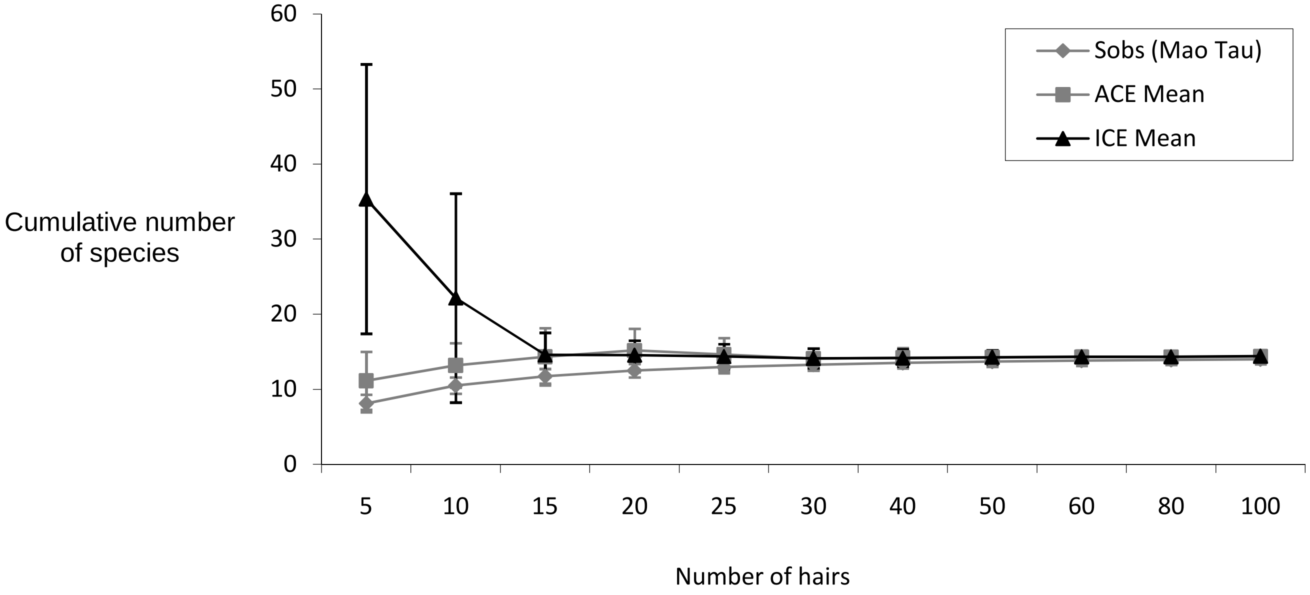

Figure 3.1: The S_{obs} (Mao Tau), incidence-based coverage estimator (ICE ± SD) and abundance-based coverage estimator (ACE ± SD) modelling the cumulative number of species against the mammalian hair sample size.

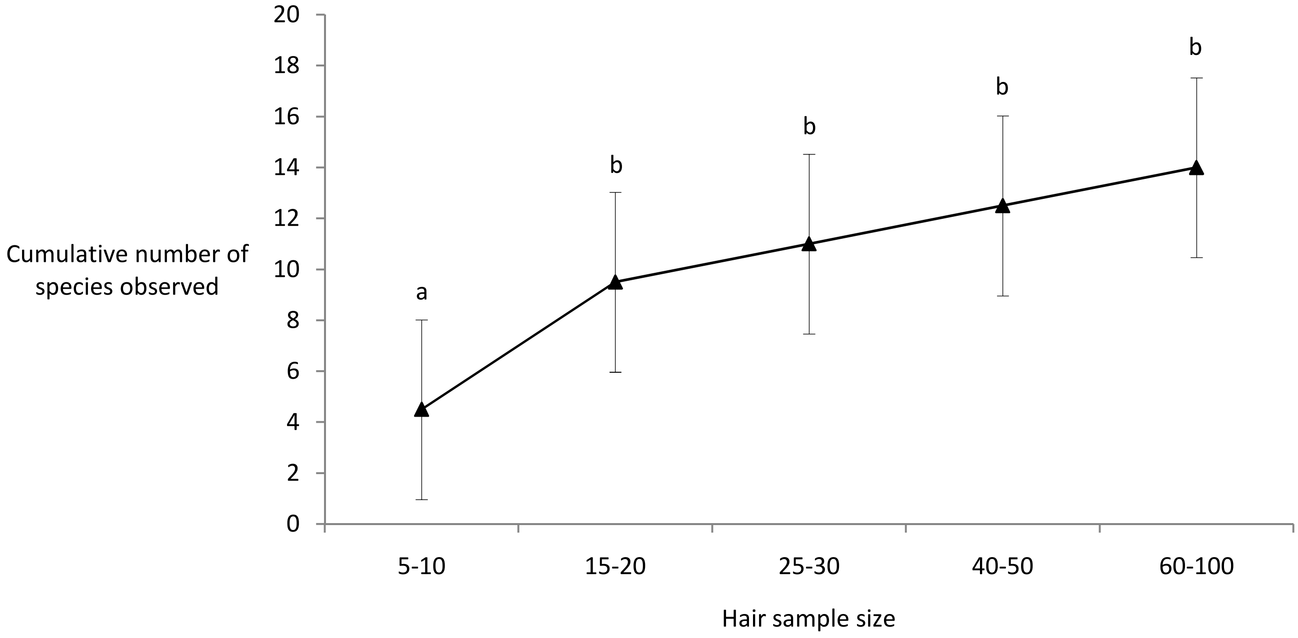

Figure 3.2: The cumulative number of species observed among five hair sample size categories. Superscript letters indicate significant differences ($p < 0.05$).

Data analysis

Dietary composition was expressed in two ways; percentage frequency of occurrence and relative percentage frequency of occurrence. Percentage frequency of occurrence was the number of scats containing a prey item divided by the total number of scats collected multiplied by 100 (Lockie 1959; Corbett 1989; Zabala & Zuberogoitia 2003). This indicates how often each dietary category occurs in the diet (Loveridge & Macdonald 2003; van der Merwe *et al.* 2009). Relative percentage frequency of occurrence was the number of occurrences of a prey category divided by the total number of occurrences of all prey categories multiplied by 100 (Lockie 1959; Aragona & Setz 2001; Giannatos *et al.* 2009). This index shows the relative occurrence of each prey category in the diet irrespective of the number of scats (Loveridge & Macdonald 2003; van der Merwe *et al.* 2009).

Other approaches for expressing dietary composition include measuring mean relative masses/volumes (Glen & Dickman 2006; Do Linh San *et al.* 2009) and biomass intake (eaten or digested) of prey items using estimations/models through conversion factors (Weaver & Hoffman 1979; Corbett 1989; Weaver 1993; Atkinson *et al.* 2002; Lanszki *et al.* 2006; Rühe *et al.* 2008; Giannatos *et al.* 2009; Lanszki *et al.* 2009). The primary limitation of using the relative volume estimation approach is the relative volumes of certain prey categories in the scat may not necessarily reflect the volume of that item upon ingestion (Mills 1996; Glen & Dickman 2006). For example, indigestible material including hair, bone and insect exoskeletons will mostly pass through the digestive tract and be reflected in the scat, whereas softer material will be largely digested. This results in the softer material prey items being under-represented in the scat volume (Mills 1996; Glen & Dickman 2006). Although measuring frequency of occurrence is not limited to the same extent by this, it is important to highlight that If prey sizes are highly variable certain prey items may be consumed frequently but in small volumes, resulting in overestimation (Corbett 1989; Weaver 1993; Ciucci *et al.* 1996; Lanszki 2005; Lanszki *et al.* 2006, Giannatos *et al.* 2009; Liu *et al.* 2010). The estimation of biomass consumed provides a more realistic measurement of the nutritive value and importance of a prey item and may be a more biologically meaningful value (Ciucci *et al.* 1996; Lanszki *et al.* 2006). However, estimating the relative biomass intake of different prey items still remains an indirect measure of diet and can over-emphasize the importance of larger prey items due to their greater biomass (Ciucci *et al.* 1996; Lanszki *et al.* 2006). In addition, it is subject to the inaccuracies of observer bias and extrapolation from materials found in the scat to whole food items (Atkinson *et al.* 2002; Giannatos *et al.* 2009). Conversion factors are available for biomass estimations when converting the dry mass/presence of certain prey items from scats into prey biomass or the number of prey items ingested (Corbett 1989; Rühe *et al.* 2008). However, they are often based on captive feeding trials and may not be appropriate for wild ranging animals living under different conditions. The majority of research on biomass estimation through model usage (Floyd *et al.* 1978; Weaver 1993) and conversion factors is restricted to North American species (Ciucci *et al.* 1996) which makes it difficult to apply them to this study. Atkinson *et al.* (2002) was one of very few studies which developed conversion factors for an African carnivore, the side-striped jackal. Although the side-striped jackal is closely related to the black-backed jackal and is likely to have similar digestive traits, the conversion factors developed were not for prey items that occur in my study area. In addition, there are other prey species occurring in my study area for which no conversion factors have been determined.

Glen & Dickman (2006) suggest that describing carnivore diets using a combination of frequency of occurrence and volumetric methods is the most useful approach. However, when Corbett (1989) compared three different methods (frequency of occurrence, relative weight of remains and biomass) of assessing the diet of dingoes, *Canis familiaris dingo,* there were no significant differences in the descriptions of the diet provided by each method. Ciucci *et al.* (1996) undertook a similar investigation when assessing the diet of the gray wolf, *Canis lupus.* The authors compared the following methods of dietary assessment: frequency of occurrence, measured mass of remains, estimated weights of remains, relative volume of remains, and the biomass ingested using two models (see Floyd *et al.* 1978 and Weaver 1993). Their results indicated no significant differences in the rank of importance of the top four prey categories when using each analytical approach. Moreover, similar results were demonstrated by van Dijk *et al.* (2007) who assessed the accuracy of four analytical methods (dry weight, the index of relative contribution based on dry weight, frequency of occurrence and percentage of occurrence) on the diet of wolverines, *Gulo gulo*. Of the four analytical approaches, the dietary descriptions provided by the frequency of occurrence and percentage of occurrence methods deviated the least from the actual diet (van Dijk *et al.* 2007). In addition, there was no significant difference in the rankings of importance of the prey categories (van Dijk *et al.* 2007).

A further advantage of the analytical approach, frequency of occurrence, is that easy comparisons with other studies on carnivore diet can be made due to its extensive use for predator dietary analyses (Grafton 1965; Corbett 1989; Glen & Dickman 2006; van Dijk *et al.* 2007; Do Linh San *et al.* 2009). Moreover, it has been documented that the relative frequency of occurrence approach produces results which closely approximate the proportions of different items actually consumed in studies that have analysed large numbers of scats (Rowe-Rowe 1983; van Dijk *et al.* 2007; Rühe *et al.* 2008). Thus, it was deemed an appropriate approach for this study.

The mean annual frequency and relative frequency of occurrence (%) of all prey categories were compared among sites. Data were divided into seasons (summer: November – February, autumn: March – May, winter: June – August, spring: September – October) to determine seasonal variation at the site level. Because sampling began in November 2009 and ended in October 2010, the November data were added to the summer sample to maintain the chronological sequence.

Statistical analysis

As the data were not all normally distributed, site and seasonal based analyses were conducted using the non-parametric Kruskal-Wallis test (Statistica™ v9.0, StatSoft 2009). Tukeys post-hoc tests were conducted to analyse where differences in mean values occurred. A Mann-Whitney U-test was conducted to determine differences in the relative frequency of occurrence of each prey category between land-use types.

3.3 RESULTS

Overall diet

A total of 562 scats (310 from Great Fish, 59 from Connaught, 163 from Shamwari and 30 from Sweetkloof) were analysed between November 2009 and October 2010. Across the four sites, black-backed jackal scats were dominated by the presence of mammal hair and vegetation (Figure 3.3). Invertebrates occurred in approximately half of the scats found on the reserves and about a quarter of the scats on the farms (Figure 3.3). Fruit and seeds were present in nearly a third of the scats collected on Great Fish but were considerably less prevalent at the other three study sites. Birds and reptiles occurred very infrequently in the scats of jackals on the reserves and were not recorded in any of the scats from the farms (Figure 3.3).

Mammal hair and vegetation remained the dominant prey items in the scats when comparing the relative contribution of each prey category (Figure 3.4). Invertebrates constituted between 10 and 20 % of all prey items in the scats across all sites. Fruit and seeds constituted less than 10 % of all prey items in the scats whilst birds and reptiles constituted less than 3 % of all prey items recorded in the scats (Figure 3.4). Large variation around the means for all prey categories at Sweetkloof farm was due to the small sample size of scats collected (n = 30).

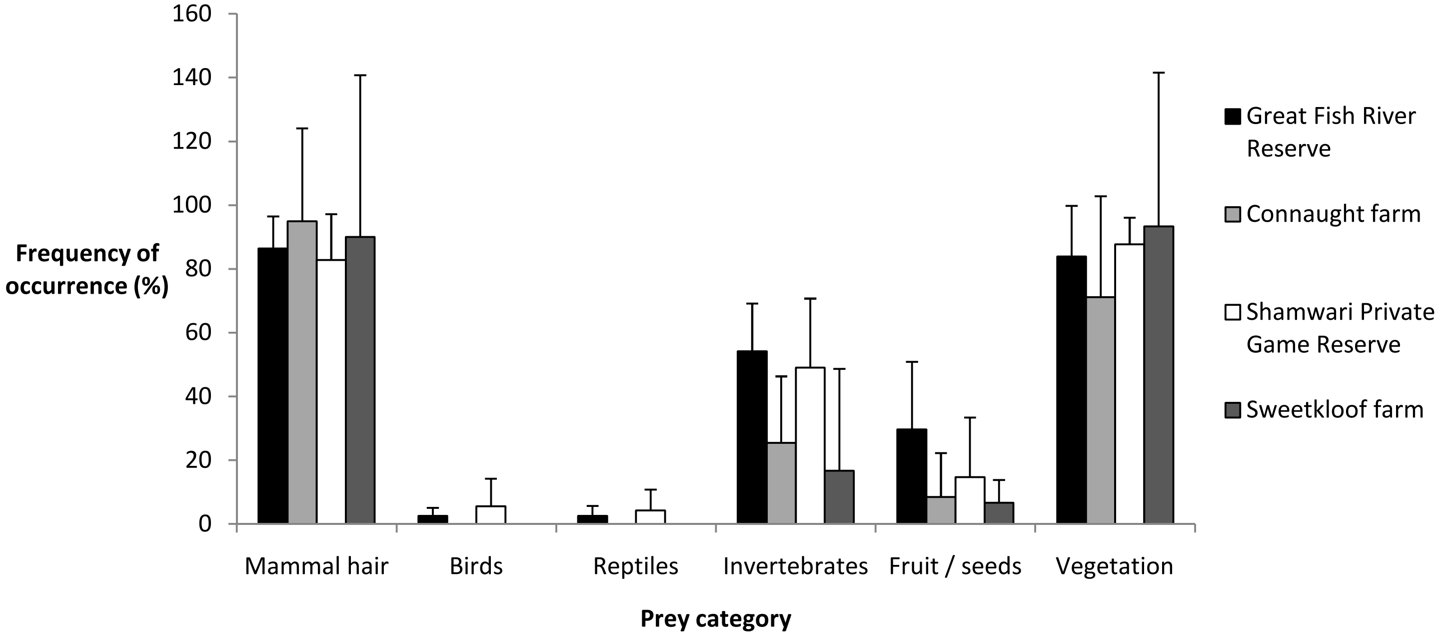

Figure 3.3: The mean (± SD) annual frequency of occurrence (%) of all prey categories across all study sites for the period November 2009 to October 2010.

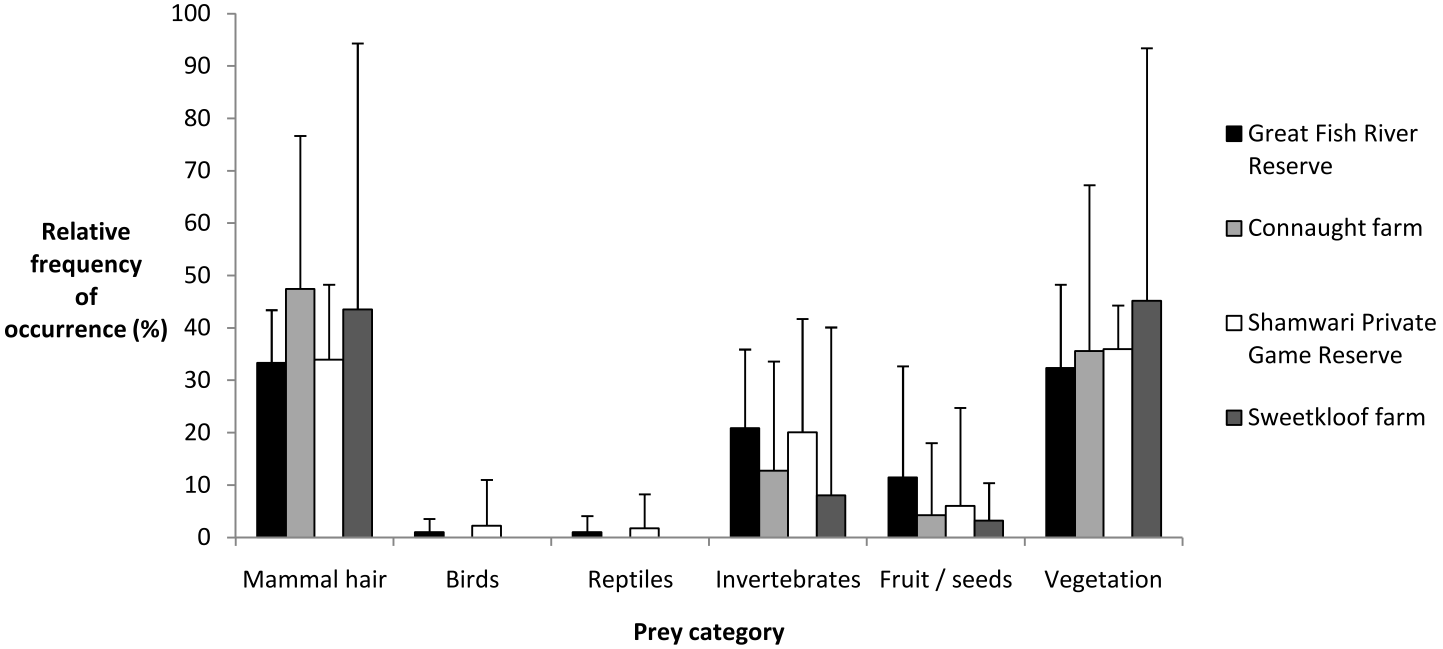

Figure 3.4: The mean (± SD) annual relative frequency of occurrence (%) of all prey categories across all study sites for the period November 2009 to October 2010.

Site comparison

All six prey categories were present in the scats from all four of the study sites except for birds and reptiles which were not recorded in the scats from either farm (Figure 3.5). There was significantly more mammal hair ($H_{3,\ 562} = 40.87$, $p < 0.05$) in the scats from the farms than the reserves (Figure 3.5). By contrast, there were significantly fewer invertebrate remains ($H_{3,\ 562} = 24.91$, $p < 0.05$) present in the scats on the reserves compared with the farms (Figure 3.5). Vegetation was significantly more prevalent ($H_{3,\ 562} = 21.20$, $p < 0.05$) in the scats at Sweetkloof compared with the other three study sites (Figure 3.5). However, this may be an artefact of the small number of scats collected from this site. There were no significant differences in the relative frequency of occurrence of birds, reptiles and fruit and seeds across the sites respectively ($p > 0.05$; Figure 3.5).

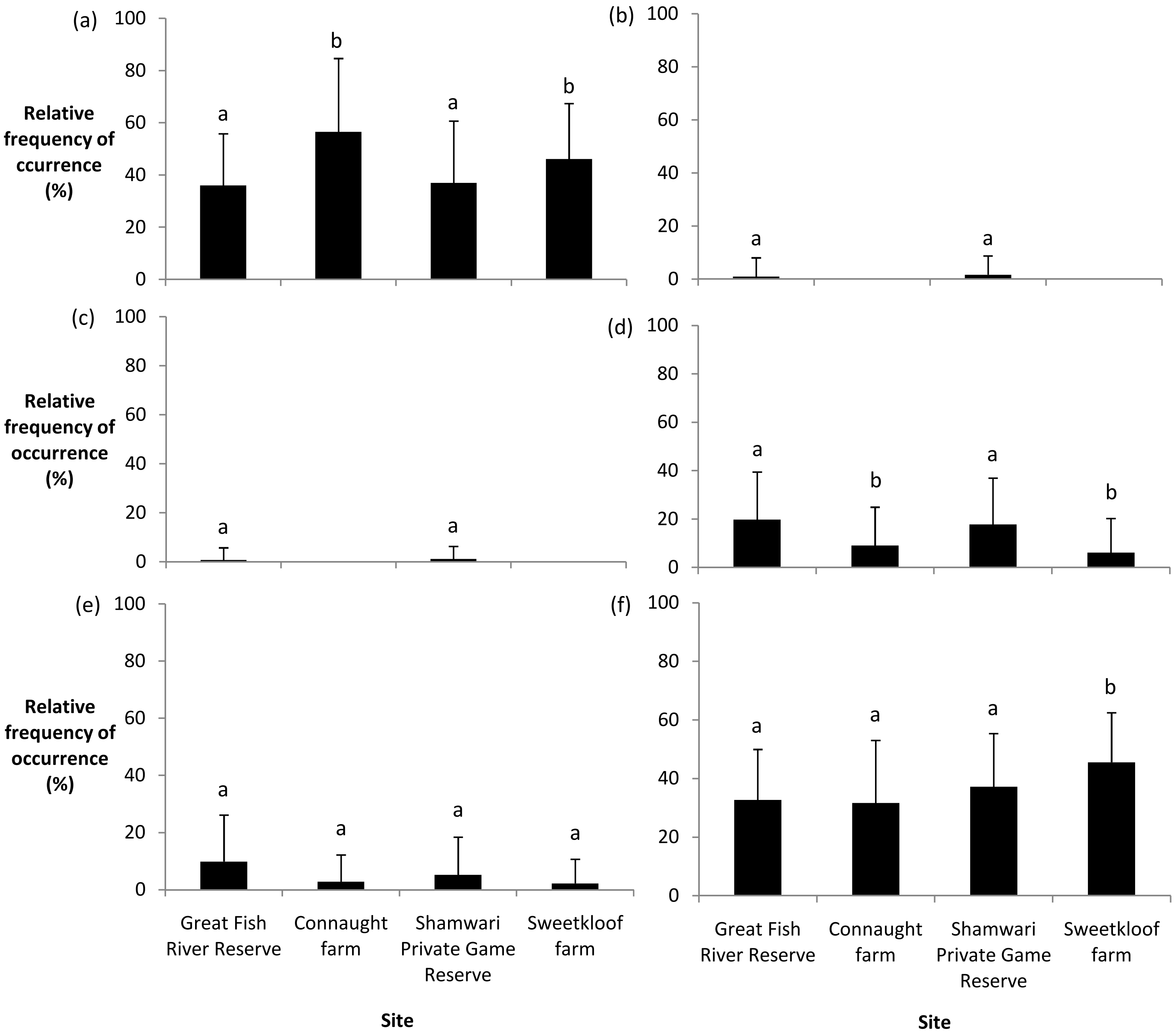

Figure 3.5: The variation in mean (± SD) relative frequency of occurrence (%) of (a) mammal hair, (b) birds, (c) reptiles, (d) invertebrates, (e) fruit / seeds and (f) vegetation across the four study sites. Superscript letters indicate significant differences ($p < 0.05$).

Seasonal comparison

Great Fish River Reserve

The relative frequency of occurrence of mammal hair in the scats across all seasons was at least 28 % at Great Fish (Figure 3.6). However, significantly more mammal hair ($H_{3,\ 310} = 11.90$, $p < 0.05$) occurred in the scats during summer (40 %) compared with spring (28 %; Figure 3.6). Invertebrates comprised at least 14 % of the overall prey items per season. However, they were significantly less common ($H_{3,\ 310} = 17.64$, $p < 0.05$) in the scats during winter (13 %) than summer (25 %; Figure 3.6). Although significantly more fruit and seeds ($H_{3,\ 310} = 28.09$, $p < 0.05$) occurred in the scats during autumn (18 %) than summer (5 %) and spring (8 %; Figure 3.6), the relative frequency of occurrence of fruit and seeds constituted between five and 18 % of the overall prey items per season. Vegetation was significantly more common in the scats ($H_{3,\ 310} = 34.84$, $p < 0.05$) during winter (37 %) and spring (41 %) compared with summer (29 %) and autumn (25 %; Figure 3.6). Birds and reptiles constituted less than 2 % of the overall prey items recorded in the scats on a seasonal basis and no reptiles were present in the scats during winter (Figure 3.6). There were no significant differences in the relative frequency of occurrence of birds or reptiles among seasons ($p > 0.05$) at Great Fish (Figure 3.6).

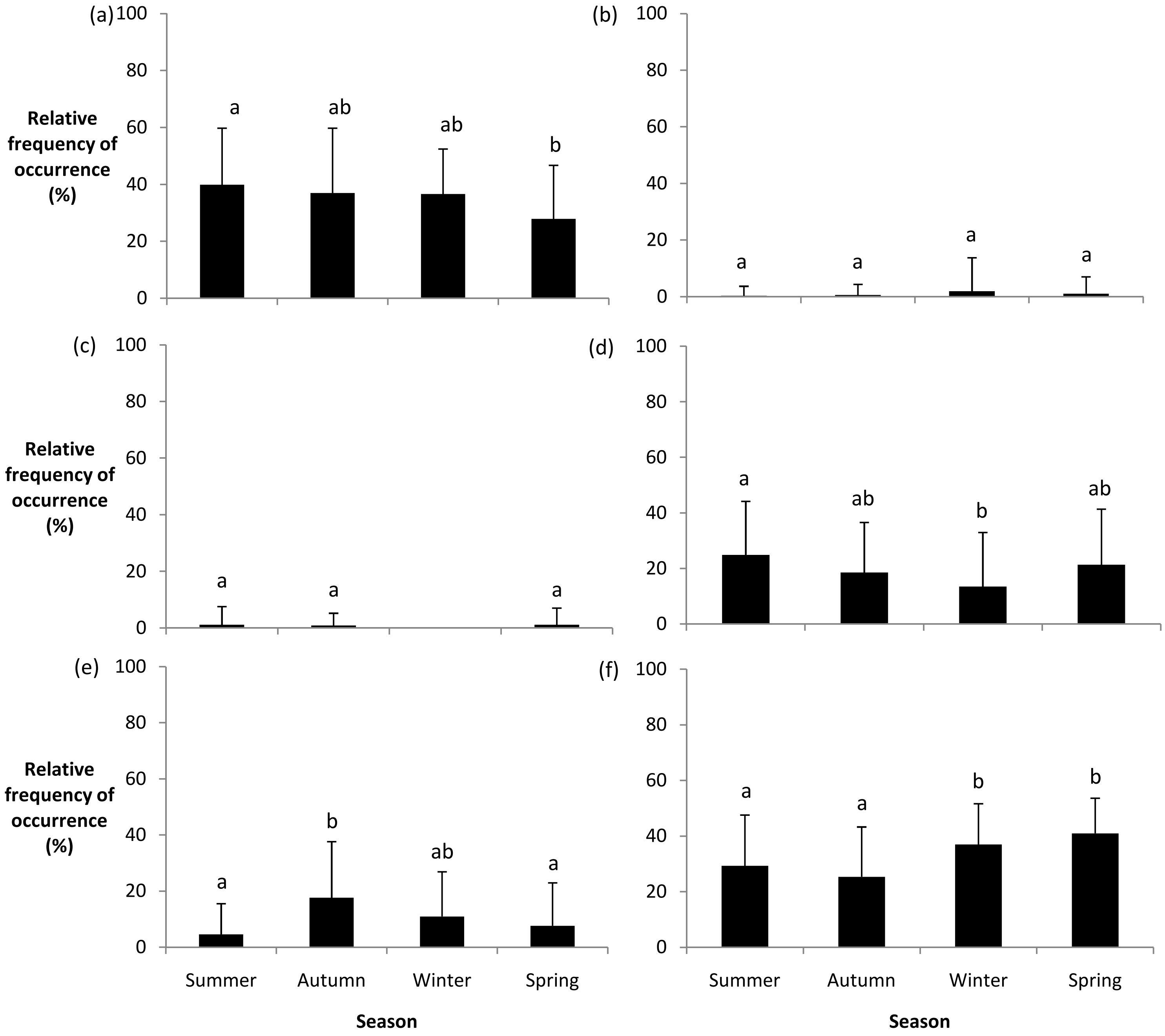

Figure 3.6: The seasonal variation in mean (± SD) relative frequency of occurrence (%) of (a) mammal hair, (b) birds, (c) reptiles, (d) invertebrates, (e) fruit / seeds and (f) vegetation at the Great Fish River Reserve. Superscript letters indicate significant differences ($p < 0.05$).

Connaught farm

The relative frequency of occurrence of mammal hair recorded in the scats ranged from 49 to 73 % across all seasons (Figure 3.7). Invertebrates comprised between four and 13 % of the overall prey items recorded per season (Figure 3.7). The relative frequency of occurrence of vegetation recorded in the scats across all seasons was at least 19 % (Figure 3.7). However, there were no significant seasonal changes in the relative frequency of occurrence of mammal hair, invertebrates, or vegetation ($p > 0.05$) in the scats from Connaught (Figure 3.7). Birds and reptiles were not recorded in the scats at this study site. Despite fruit and seeds comprising between 4 and 6 % of the prey items in autumn and spring and not being present in the scats during summer or winter, there was no significant difference in the relative frequency of occurrence of this prey item between seasons ($p > 0.05$; Figure 3.7).

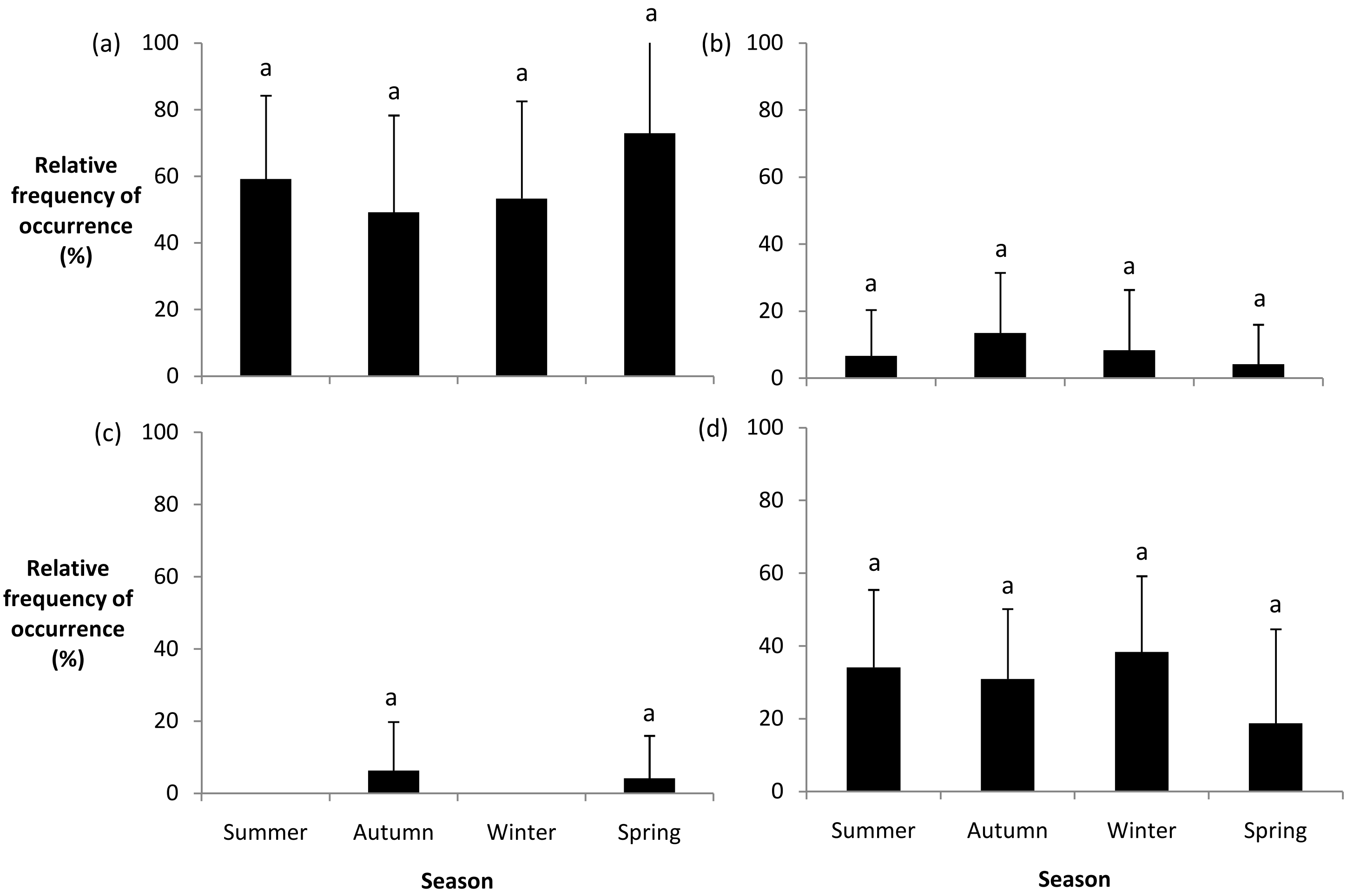

Figure 3.7: The seasonal variation in mean (± SD) relative frequency of occurrence (%) of (a) mammal hair, (b) invertebrates, (c) fruit / seeds and (d) vegetation on Connaught farm. Superscript letters indicate significant differences ($p < 0.05$).

Shamwari Private Game Reserve

The relative frequency of occurrence of mammal hair recorded in the scats across all seasons ranged from 28 to 45 % (Figure 3.8). However, significantly more mammal hairs ($H_{3,\ 163} = 5.87$, $p < 0.05$) were present in the scats during winter (45 %) compared with autumn (32 %) and spring (28 %; Figure 3.8). Invertebrates comprised between eight and 30 % of the prey items per season at Shamwari (Figure 3.8). They were significantly more common ($H_{3,\ 163} = 28.70$, $p < 0.05$) in the scats during spring (30 %) than summer (16 %) and winter (8 %; Figure 3.8). Despite vegetation constituting at least 33 % of the prey items per season, the prevalence of vegetation in the scats demonstrated a significant peak ($H_{3,\ 163} = 10.72$, $p < 0.05$) during winter (44 %) compared with summer (33 %; Figure 3.8). Birds and reptiles comprised less than 3 % of the prey items per season respectively (Figure 3.8). Furthermore, reptiles were not present in the scats during autumn (Figure 3.8). There were no significant differences between seasons for birds or reptiles ($p > 0.05$). Fruit and seeds constituted no more than 13 % of the overall prey items per season and there were no significant seasonal changes ($p > 0.05$; Figure 3.8).

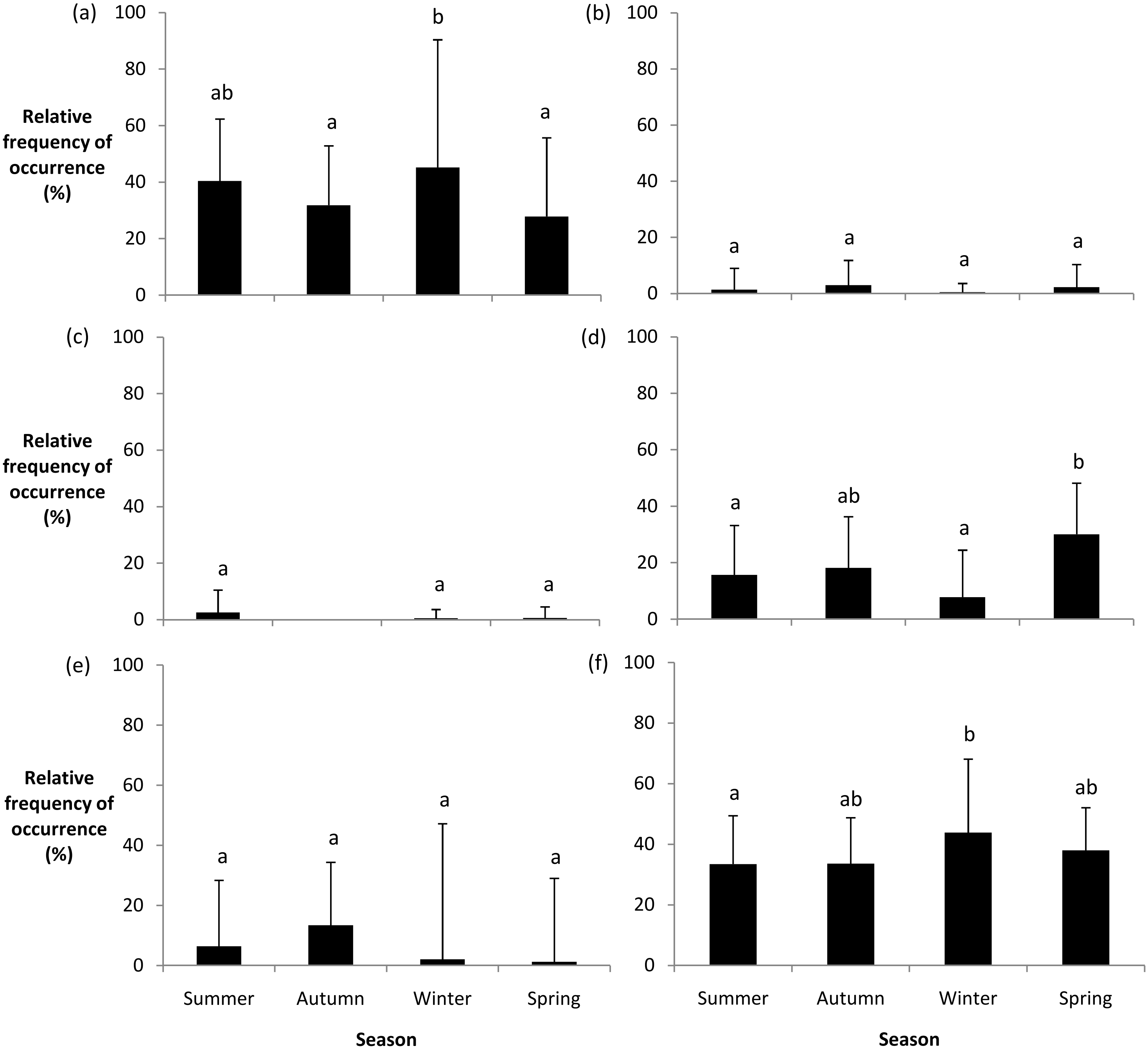

Figure 3.8: The seasonal variation in mean (± SD) relative frequency of occurrence (%) of (a) mammal hair, (b) birds, (c) reptiles, (d) invertebrates, (e) fruit / seeds and (f) vegetation on Shamwari Private Game Reserve. Superscript letters indicate significant differences ($p < 0.05$).

Sweetkloof farm

No scats were collected during autumn. Mammal hair constituted at least 33 % of the overall prey items per season at Sweetkloof. Invertebrates constituted considerably less (11 %) of the prey items recorded per season (Figure 3.9). However, there were no significant seasonal differences in the relative frequency of occurrence of mammal hair or invertebrates between seasons ($p > 0.05$; Figure 3.9). Fruit and seeds were only recorded in scats collected in winter during which they constituted only 4 % of the overall prey items for that season. Furthermore, there were no significant differences in their relative frequency of occurrence between seasons ($p > 0.05$; Figure 3.9). The relative frequency of occurrence of vegetation recorded in the scats across all seasons was at least 41 % (Figure 3.9). However, there were no significant seasonal differences ($p > 0.05$). Birds and reptiles were not recorded in the scats at this study site (Figure 3.9).

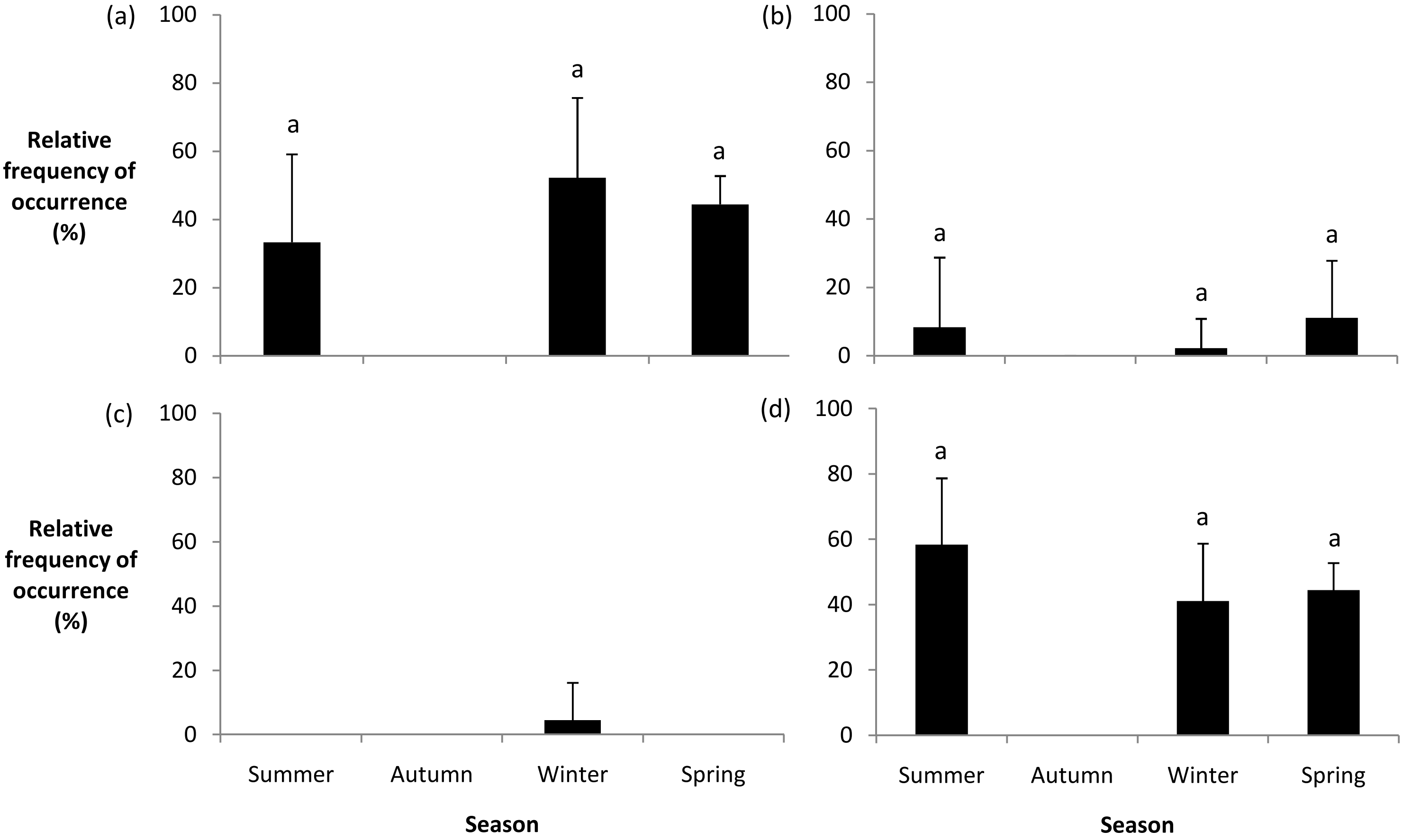

Figure 3.9: The seasonal variation in mean (± SD) relative frequency of occurrence (%) of (a) mammal hair, (b) invertebrates, (c) fruit / seeds and (d) vegetation on Sweetkloof farm. Superscript letters indicate significant differences ($P < 0.05$).

Land-use type comparison

There was a significantly higher relative frequency of occurrence of mammal hair ($U_{n1=473,\ n2=89}$ = 12584.0, $p < 0.05$) in the scats collected on the farmlands (53 %) compared with the reserves (36 %; Figure 3.10). Similarly, vegetation was significantly more prevalent ($U_{n1=473,\ n2=89}$ = 17962.50, $p < 0.05$) in the scats on farmland (36 %) compared with the reserves (34 %; Figure 3.10). By contrast, the relative frequency of occurrence of invertebrates recorded in the scats from the reserves (19 %) was significantly higher ($U_{n1=473,\ n2=89}$ = 14835.50, $p < 0.05$) than the farmlands (8 %; Figure 3.10). Although fruit and seeds only constituted eight and 3 % of the overall prey items recorded in the scats from the reserves and farmlands respectively, there were significantly more fruit and seeds ($U_{n1=473,\ n2=89}$ = 17608.50, $p < 0.05$) present in the scats on the reserves (Figure 3.10). Despite the relative frequency of occurrence of bird remains in the scats being higher on the farmlands (12 %) than on the reserves (1 %), there was no significant difference between the two land-use types ($p > 0.05$; Figure 3.10).

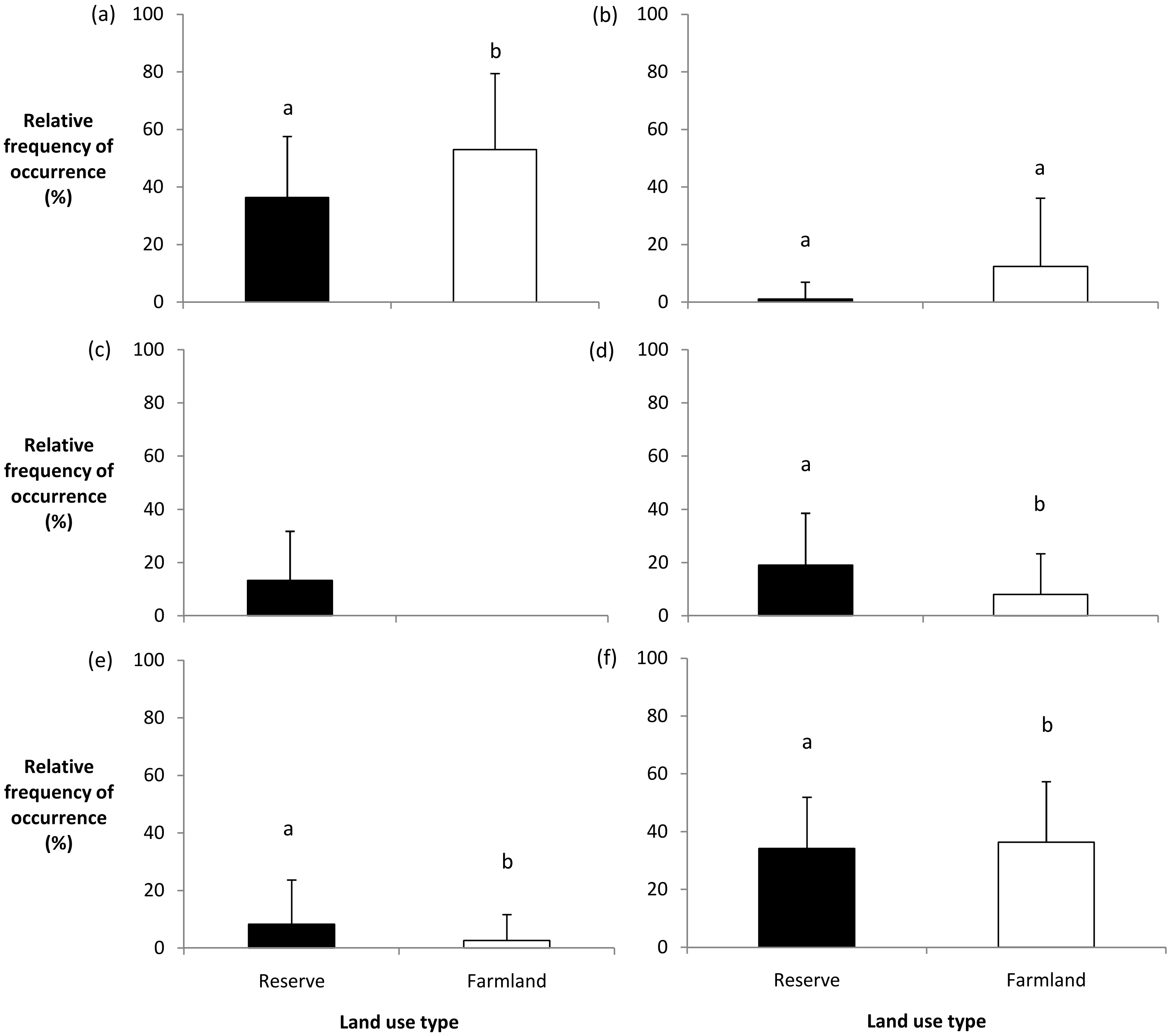

Figure 3.10: The mean (± SD) relative frequency of occurrence (%) of (a) mammal hair, (b) birds, (c) reptiles, (d) invertebrates, (e) fruit / seeds and (f) vegetation across two contrasting land-use types; reserves and farmland. Superscripts indicate significant differences ($p < 0.05$).

Mammal hair

The mammal hair prey category comprised at least 17 different species from five different orders (Table 3.1). Six different species of ruminant and seven species of rodent were identified (Table 3.1). The suiformes, carnivores and lagomorphs comprised a single species respectively (Table 3.1). Dorper sheep wool and Angora goat hairs were also recorded in the scats and although they are ruminants, for the purpose of this study, they were classified under a livestock category (Table 3.1).

Ruminants, carnivores and rodents were recorded at all four study sites (Table 3.1). Bushbuck *Tragelaphus scriptus* was the most commonly recorded (> 4.4 % RFO) ruminant species at each site (Table 3.1). Greater kudu was the only other ruminant recorded in the scats at all the sites comprising between 0.3 and 1.7 % (RFO) of the mammal hair prey category (Table 3.1). All other ruminants (common duiker *Sylvicapra grimmia*, springbok, steenbok and impala) constituted less than 2 % of the mammal hair prey category at each site (Table 3.1). Springbok and impala were only recorded in the scats from Shamwari and steenbok was only recorded at Great Fish and Connaught (Table 3.1).

Black-backed jackal was the only carnivore species identified in the scats and constituted at least 12 % (RFO) of the mammalian hair prey category at each site (Table 3.1).

The species composition of the rodents was dominated by the vlei rat and the four-striped grass mouse *Rhabdomys pumilio* comprising up to 4.1 % (RFO) of the mammal hair prey category per site respectively (Table 3.1). Five other rodent species were identified across the study sites; Cape porcupine *Hystrix africaeaustralis*, springhare *Pedetes capensis*, natal multimammate mouse *Mastomys natalensis*, pouched mouse *Saccostomus campestris* and house rat *Rattus rattus*. Although at least four species were identified at each site, they constituted varying portions (2.7 – 7.5 %) of the mammal hair prey category depending on the site (Table 3.1). Unlike the other three study sites, the species composition of the rodents at Sweetkloof was represented by one species, the vlei rat (Table 3.1).

Warthog hair was recorded in the scats from all the study sites except Sweetkloof. However, this species only constituted a very small portion (< 1.7 %) of the mammal hair prey category per site (Table 3.1).

Scrub hare *Lepus saxatilis* (Lagomorpha) was only recorded on Shamwari and formed a very small portion (1 %) of the mammal hair prey category (Table 3.1).

Livestock hair was recorded in the scats at all study sites except Great Fish and constituted a large proportion of the mammal hair prey category on Connaught (10.4 %) and Sweetkloof (12.8 %) respectively (Table 3.1). By contrast, livestock represented a very small portion (0.3 %) of the mammal prey category at Shamwari (Table 3.1). Angora goat hairs were absent from the scats at all sites except Connaught (Table 3.1). Dorper sheep wool was considerably more common (7.6 %) in the scats compared with Angora goat hair at Connaught (2.8 %; Table 3.1).

Unidentified mammals formed between 1.3 and 3.4 % of the mammal hair prey category recorded at each site (Table 3.1).

Table 3.1: The species composition of the mammal hair prey category recorded in the scats at each of the four study sites. *n* = number of scats collected at each site, N = absolute number of occurrences, and RFO = relative frequency of occurrence (%). Nomenclature follows Skinner & Chimimba (2005).

	Site								
	Great Fish River Reserve (*n* = 310)		**Connaught farm (*n* = 59)**		**Shamwari Private Game Reserve (*n* = 143)**		**Sweetkloof farm (*n* = 30)**		**Total**
Species	**N**	**RFO**	**N**	**RFO**	**N**	**RFO**	**N**	**RFO**	**N**
Mammal	***100***	***33.3***	***100***	***47.5***	***100***	***33.9***	***75***	***43.6***	***375***
Lagomorpha	***0***	***0.0***	***0***	***0.0***	***3***	***1.0***	***0***	***0.0***	***3***
scrub hare	0	0.0	0	0.0	3	1.0	0	0.0	*3*
Rodentia	***8***	***2.7***	***7***	***3.3***	***22***	***7.5***	***7***	***4.1***	***44***
Cape porcupine	1	0.3	1	0.5	1	0.3	0	0.0	*3*
springhare	0	0.0	2	0.9	0	0.0	0	0.0	*2*
four-striped grass mouse	4	1.3	2	0.9	9	3.1	0	0.0	*15*
Natal multimammate mouse	2	0.7	0	0.0	0	0.0	0	0.0	*2*
vlei rat	1	0.3	1	0.5	9	3.1	7	4.1	*18*
pouched mouse	0	0.0	1	0.5	2	0.7	0	0.0	*3*
house rat	0	0.0	0	0.0	1	0.3	0	0.0	*1*
Carnivora	***37***	***12.3***	***31***	***14.7***	***37***	***12.6***	***23***	***13.4***	***128***
black-backed jackal	37	12.3	31	14.7	37	12.6	23	13.4	*128*
Suiformes	***5***	***1.7***	***2***	***0.9***	***4***	***1.4***	***0***	***0.0***	***11***
common warthog	5	1.7	2	0.9	4	1.4	0	0.0	*11*
Ruminantia	***46***	***15.3***	***35***	***16.6***	***23***	***7.8***	***20***	***11.6***	***124***
Greater kudu	5	1.7	3	1.4	1	0.3	2	1.2	*11*
bushbuck	35	11.7	31	14.7	13	4.4	16	9.3	*95*
common duiker	3	1.0	0	0.0	6	2.0	2	1.2	*11*
springbok	0	0.0	0	0.0	2	0.7	0	0.0	*2*
steenbok	3	1.0	1	0.5	0	0.0	0	0.0	*4*
impala	0	0.0	0	0.0	1	0.3	0	0.0	*1*
Livestock	***0***	***0.0***	***22***	***10.4***	***1***	***0.3***	***22***	***12.8***	***45***
dorper sheep	0	0.0	16	7.6	1	0.3	22	12.8	*39*
Angora goat	0	0.0	6	2.8	0	0.0	0	0.0	*6*
Unidentified	***4***	***1.3***	***3***	***1.4***	***10***	***3.4***	***3***	***1.7***	***20***

Invertebrates

Three classes of invertebrates were recorded in the scats across the study sites including insecta, arachnida and diplopoda (Table 3.2). However, the invertebrates consisted predominantly of insects ranging from 6.9 to 20.2 % (RFO) per site (Table 3.2). Three orders of insects were identified including the isoptera, orthoptera and coleoptera. Only the isoptera and coleoptera were recorded at all sites and the orthoptera were absent from both farms (Table 3.2). The coleoptera constituted the largest portion of the insect class across all sites ranging from 4.6 to 14.9 % (RFO) (Table 3.2). By comparison, the orthoptera constituted a smaller portion (0.8 – 2.0 % RFO) of the insect class than the isoptera (2.3 – 7.1 % RFO; Table 3.2).

Arachnids were only recorded in the scats from Sweetkloof and constituted a very small portion (1.2 % RFO) of the invertebrate prey category (Table 3.2). Similarly, millipedes (diplopoda) were only recorded in the scats from Great Fish and they also constituted a very small portion (0.6 % RFO) of the invertebrate prey category (Table 3.2).

Unidentified invertebrates were only recorded in the scats collected at Great Fish and represented only 0.1 % (RFO) of the invertebrate prey category (Table 3.2).

Table 3.2: The composition of the invertebrate prey category recorded in the scats at each of the four study sites. The insects, arachnids and diplopods are classified to order level. *n* = number of scats collected at each site, FO = frequency of occurrence (%), and RFO = relative frequency of occurrence (%).

	Site							
	Great Fish River Reserve		**Connaught farm**		**Shamwari Private Game Reserve**		**Sweetkloof farm**	
	(*n* = 310)		**(*n* = 59)**		**(*n* = 143)**		**(*n* = 30)**	
	%		**%**		**%**		**%**	
Order	**FO**	**RFO**	**FO**	**RFO**	**FO**	**RFO**	**FO**	**RFO**
Invertebrate	***54.2***	***20.9***	***25.4***	***12.7***	***49.1***	***20.1***	***16.7***	***8.1***
Insecta	***52.4***	***20.2***	***25.4***	***12.7***	***49.1***	***20.1***	***14.3***	***6.9***
Isoptera	18.3	7.1	6.4	3.2	10.7	4.4	4.8	2.3
Orthoptera	5.2	2.0	0.0	0.0	2.0	0.8	0.0	0.0
Coleoptera	28.8	11.1	19.1	9.5	36.3	14.9	9.5	4.6
Arachnida	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***2.4***	***1.2***
Scorpiones	0.0	0.0	0.0	0.0	0.0	0.0	2.4	1.2
Diplopoda	***1.6***	***0.6***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***
Spirostreptida	1.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified	***0.3***	***0.1***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***

Fruit and seeds

At least 10 species of fruit and seed were identified in the scats across all study sites. The highest number of species was recorded at Great Fish (10) compared with Connaught (2), Shamwari (4), and Sweetkloof (2) respectively. The mean annual (± SD) number of fruit and seeds recorded in the scats across the four study sites was 35 ± 50.3. The highest number of fruit and seeds recorded in the scats per site (109) was at Great Fish (Table 3.3). Considerably fewer fruit and seeds were recorded in the scats at Connaught (5), Shamwari (24), and Sweetkloof (2) respectively (Table 3.3).

Karoo crossberry *Grewia robusta* was the only species to be recorded in the scats collected at all the study sites (Table 3.3). Furthermore, it was the most frequently recorded species in the scats from Great Fish (54.1 % RFO) and Connaught (80.0 % RFO; Table 3.3). Bluebush *Diospyros lycioides* (50 %) and *G. robusta* (50 %) were recorded species in equal proportions in the scats at Sweetkloof (Table 3.3). Similar to Sweetkloof, *D. lycioides* was the most frequently recorded species (87.5 %) in the scats from Shamwari (Table 3.3). However, this was followed by equal occurrences of *G. robusta* (4.2 %), bush cherry *Maerua caffra* (4.2 %) and the jacket-plum *Pappea capensis* (4.2 %) (Table 3.3). Sweet thorn *Acacia karroo* was the only other species recorded at Connaught constituting 20 % of the fruit and seeds identified at that site (Table 3.3).

Maerua caffra and *P. capensis* were only recorded in the scats from the reserves and *D. lycioides* was only recorded at Shamwari and Sweetkloof (Table 3.3). Although only one seed of *A. karroo* was recorded at Great Fish (0.9 %) and Connaught (20 %) respectively, this species was not recorded at Shamwari or Sweetkloof (Table 3.3).

Six species were recorded in the scats from Great Fish, including Karoo num-num *Carissa haematocarpa* (11.0 %), Kooboo-berry *Mystroxlyon aethiopicum* (1.8 %), orange jasmine *Murraya paniculata* (2.8 %), false spike-thorn *Putterlickia pyracantha* (1.8 %) and baboon grape *Rhoicissus digitata* (1.8 % ; Table 3.3).

Only 17 of the 140 fruit and seeds recorded in the scats remained unidentified (Table 3.3).

Table 3.3: The species classification of fruit and seeds recorded in the scats at each of the four sites for each season during the study period, November 2009 to October 2010. *n* = the number of scats containing fruit / seeds collected at each site, N = absolute number of occurrences and RFO = relative frequency of occurrence (%). Nomenclature follows van Wyk & van Wyk (1997).

	Species																							
	Acacia karroo		*Carissa haematocarpa*		*Mystroxylon aethiopicum*		*Diospyros lycioides*		*Grewia robusta*		*Maerua cafra*		*Murraya paniculata*		*Pappea capensis*		*Putterlickia pyracantha*		*Rhoicissus digitata*		Unidentified		**Total**	
Site	**N**	**RFO**	**N**	**RFO**	**N**	**RFO**	**N**	**RFO**	**N**	**RFO**	**N**	**RFO**	**N**	**RFO**	**N**	**RFO**	**N**	**RFO**	**N**	**RFO**	**N**	**RFO**	**N**	**RFO**
Great Fish River Reserve *(n = 89)*	1	0.9	12	11.0	2	1.8	0	0.0	59	54.1	1	0.9	3	2.8	10	9.2	2	1.8	2	1.8	17	15.6	**109**	**99.9**
Connaught farm (*n* = 5)	1	20.0	0	0.0	0	0.0	0	0.0	4	80.0	0	0.0	0	0.0	0	0.0	0	0.0	00	0.0	0	0.0	**5**	**100.0**
Shamwari Private Game Reserve (*n* = 24)	0	0.0	0	0.0	0	0.0	21	87.5	1	4.2	1	4.2	0	0.0	1	4.2	0	0.0	0	0.0	0	0.0	**24**	**100.1**
Sweetkloof farm (*n* = 2)	0	0.0	0	0.0	0	0.0	1	50.0	1	50.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	**2**	**100.0**
Total	**2**		**12**		**2**		**22**		**65**		**2**		**3**		**11**		**2**		**2**		**17**			

3.4 DISCUSSION

Overall diet

The findings of this study are in agreement with previous research describing the diet and foraging habits of black-backed jackal in sub-Saharan Africa (Shortridge 1934; Grafton 1965; Bothma 1971b; Rowe-Rowe 1976; Hall-Martin & Botha 1980; Kaunda & Skinner 2003; Loveridge & Macdonald 2003; Do Linh San *et al.* 2009; van der Merwe *et al.* 2009; Klare *et al.* 2010). Furthermore, the dominant prey items recorded in their diet in this study; mammal hair and vegetation, were also the principal dietary items recorded in their diet in other studies (Grafton 1965; Bothma 1971b; Stuart 1981; Rowe-Rowe 1983; Smithers 1983; Stuart 1987; Kaunda & Skinner 2003; Do Linh San *et al.* 2009; Klare *et al.* 2010). The secondary prey items recorded in their diet in this study were the invertebrates and fruit and seeds. However, the prevalence of these food items in the diet of black-backed jackals has demonstrated considerably more variation as a result of seasonal and habitat variation (Grafton 1965; Stuart *et al.* 1976; Nel *et al.* 1997; Bothma *et al.* 1984; Kaunda & Skinner 2003; Klare *et al.* 2010). Moreover, the incidences of the food items least prevalent in their diet in this study (birds and reptiles) have also been particularly variable in previous studies (Stuart *et al.* 1976; Avery *et al.* 1987). It would therefore appear that birds and reptiles are not particularly important prey items for black-backed jackals in this part of the Eastern Cape and their presence in the diet is an example of their opportunistic foraging habits (Rowe-Rowe 1983; Loveridge & Macdonald 2003; Skinner & Chimimba 2005).

Seasonal comparison

The seasonal variation observed in the diet of the black-backed jackals in this study can be attributed to their opportunistic foraging ability (Rowe-Rowe 1983; Nel et al. 1997; Kaunda & Skinner 2003; Loveridge & Macdonald 2003; Loveridge & Nel 2004) allowing the species to adapt to spatio-temporal variations in prey availability as predicted by the optimal foraging theory (MacArthur & Pianka 1966; Pyke *et al.* 1977; Stephen & Krebs 1986). According to Herbst & Mills (2010), prey abundance, their activity cycles, their accessibility and their energy content all influence a predator's diet choice and hunting strategy. This was evident in the seasonal comparisons of the relative frequency of occurrence of the different prey items in the diet of black-backed jackals in this study. A marked seasonal dietary switch was observed at Great Fish where the prevalence of fruit and seeds in the scats increased significantly during autumn while the prevalence of mammal hair and invertebrates decreased. Similarly, during winter, significant declines in the frequency of fruit and seeds, and invertebrates in the scats were contrasted by simultaneous increases in the presence of mammal hair and vegetation.

The Eastern Cape receives the majority of its rainfall in the first of two annual peaks during autumn (Kopke 1988; Stone *et al.* 1998). The flowering of a number of plant species in the dominant thicket biome during the previous summer season combined with the rainfall in autumn results in their fruiting at this time and an increase in the availability of this resource (van Wyk & van Wyk 1997). As a generalist predator capitalising on those prey items which are in greatest abundance and most easily acquired, the jackals in this study evidently took advantage of the abundance of the fruit and seeds during this season at Great Fish as seen in the scats (Kaunda & Skinner 2003; Klare *et al.* 2010). A similar trend was also observed by Klare *et al.* (2010) who reported seasonal changes in the prevalence of fruit and seeds in the diet of black-backed jackals to peak during autumn linked to the fruiting season in the Northern Cape Province, South Africa. Furthermore, the higher availability and consumption of fruits was linked to a decrease in the predation of ungulates (Klare *et al.* 2010) which may explain the decrease in mammal hair in the diet during autumn observed at Great Fish in this study.

As the dominant group of invertebrates observed in the diet in this study were the insects, the decline in the prevalence of invertebrates in the diet during autumn can be explained by the reduction in insect activity approaching the winter season (Picker *et al.* 2004; Gullan & Cranston 2005). Furthermore, the composition of insects consumed across all sites was dominated by the coleopterans which, as observed by Hall-Martin & Botha (1980), were more common during spring and summer in this region of the Eastern Cape as a result of the new growth of the herb layer and further explains their prevalence in the diet during these periods. Intermittent rainfall events combined with warm conditions during spring and summer corresponds to the emergence of termites (Picker *et al.* 2004) and may account for the increase of the isoptera observed in the diet during these periods.

The increase in the incidence of vegetation observed in the diet during winter may be due to other prey items becoming less available or to assist in the mechanical process of digestion (Smithers 1983).

Interestingly, the increase in the prevalence of mammal hair recorded in the diet during winter at Great Fish was dominated by the ungulates (Appendix A). Considering that other resources (e.g. fruit and seeds, and invertebrates) become less available during this season (van Wyk & van Wyk 1997; Picker *et al.* 2004), black-backed jackals evidently either capitalised on more available scavenging opportunities of ungulate carcasses or hunted ungulates to meet their dietary requirements. According to Bernard & Stuart (1992), ungulate carrion becomes more available in the Eastern Cape during winter due to the harshness of the weather and may explain the observed increase in the mammalian component of the diet. A similar trend was observed in the study by Rowe-Rowe (1983) who reported that most ungulates consumed by black-backed jackals during winter in KwaZulu-Natal were scavenged from animals that had succumbed to the harshness of the weather. By contrast, Wyman (1967) reported the higher proportion of ungulates in the diet of black-backed jackals in Ngorongoro Crater (Tanzania) to be attributed to scavenging off high numbers of carcasses as a result of high concentrations of large carnivores as opposed to seasonally linked ungulate mortality. However, although anecdotal accounts exist of large carnivores (e.g. leopards and brown hyaena) occurring at Great Fish, their densities are too low to explain the increased prevalence of mammal hair (from increased carrion) in the diet of jackals during this season. Black-backed jackals are also known to hunt larger (> 15 kg) ungulate prey when other food resources are less abundant (Wyman 1967; Sleicher 1973; Lamprecht 1978; Moehlman 1983; McKenzie 1990; Walton & Joly 2003; Skinner & Chimimba 2005; Kamler *et al.* 2009). However, direct observations are required to verify this contention. Thus, a more likely explanation for the increase in mammal hair observed in the diet during winter in this study is probably a combination of the species both hunting larger ungulates and scavenging.

Of the ruminants recorded in the diet of black-backed jackals in this study, the bushbuck was the most common. Bushbuck are particularly common in the study area (Skinner & Chimimba 2005) and thus should be a readily available prey item for black-backed jackals. In addition, it is a 'hider' species which conceals its young in dense bush for up to four months during a period of post-natal concealment (Estes 1991). This behaviour increases the likelihood of predation as the searching behaviour of jackals is adapted to finding the young of 'hider' species (Lamprecht 1978). The combination of high bushbuck abundance and their 'hider' behaviour may therefore explain the high prevalence of bushbuck recorded in the diet of black-backed jackals in this study compared with other ungulates. However, scat analysis is not capable of determining the age-class of the mammals recorded in their diet or whether they were hunted or scavenged (Bowland & Bowland 1991; Mills 1996) and direct observations would be necessary for clarification of this suggestion.

Similar to Great Fish, marked seasonal variation in the prey categories consumed by black-backed jackals was observed at Shamwari. An increase in the prevalence of fruit and seeds was recorded in the diet during autumn. However, this change was not significant and may be attributed to the small number of seeds recorded in the scats at Shamwari (24 seeds) compared with Great Fish (109 seeds).

Significant increases in the prevalence of mammal hair and vegetation recorded in the diet during winter were also observed at Shamwari. This occurred in conjunction with a significant decline in the frequency of invertebrates in the diet. The increase in the prevalence of mammal hair may be attributed to a lack of other resources being available during this season (Loveridge & Macdonald 2003; Kaunda & Skinner 2003). However, although it appears as though more mammals were consumed during winter at Shamwari, the species composition of mammals consumed during this season indicates it was dominated by black-backed jackal hair (22.5 %) (Appendix B). Therefore, although it may appear as if there has been an increase in the consumption of mammals during this season, this was not the case. Although intra-specific predation is a possible explanation for the increased prevalence of black-backed jackal hair in the diet (Moehlman 1983), no cases of cannibalism have been reported (Kaunda & Skinner 2003; Klare *et al.* 2010). Instead, black-backed jackals are known to groom both themselves and their conspecifics (allogrooming) and any black-backed jackal hairs found in the scats were therefore presumed to be ingested during grooming (Kaunda & Skinner 2003; Walton & Joly 2003).

The seasonal dietary switching observed on both reserves in this study is similar to the findings of Kaunda & Skinner (2003). In their study at Mokolodi Nature Reserve, Botswana, the authors reported significant increases in the incidence of mammals and declines in the prevalence of invertebrates and fruit and seeds in the diet of black-backed jackals during winter (Kaunda & Skinner 2003). In addition, a significant increase in the prevalence of invertebrates was also recorded in the diet during the summer by Kaunda & Skinner (2003), further supporting the findings of my study. Similar seasonal dietary switching was reported by Loveridge & Macdonald (2003) for black-backed jackals in north-west Zimbabwe and by Rowe-Rowe (1983) in KwaZulu-Natal, South Africa. The seasonal dietary shifts of black-backed jackals observed in this study have also been reported for other jackal species (Wyman 1967; Lamprecht 1978; Atkinson *et al.* 2002; Lanszki *et al.* 2006, 2009). Furthermore, this phenomenon has been reported to occur widely in the diets of other generalist canids, including the African wild dog (Kruger *et al.* 1999), the maned wolf *Chrysocyon brachyurus* (Aragona & Setz 2001) and the red fox, *Vulpes vulpes* (Dell'Arte *et al.* 2007).

Significantly, no seasonal dietary shifts were observed on either of the farms. This may be attributed to an inadequate number of scats collected at each site (Trites & Joy 2005) as a result of only small populations of black-backed jackals occurring on the farmlands.

Land-use type comparison

The diet of black-backed jackals recorded on the reserves comprised significantly more invertebrates and fruit and seeds compared with the farmlands. This was contrasted with significantly more mammal hair and vegetation recorded in the diet of farmland jackals. Thus, it can be concluded that land-use type is likely to influence the diet of black-backed jackals in the Eastern Cape.

The grazing activities of livestock reduce the herb layer on farmland (Skarpe 1986; Fynn & O'Connor 2000; Skarpe 2000) which is associated with a reduction in the abundance of invertebrates (Kruess & Tscharntke 2002; Blaum *et al.* 2007; Blaum et al. 2009a; Wallgren *et al.* 2009). Assuming that the farms are more heavily stocked than the reserves and therefore experience heavier grazing pressure, this may explain the higher prevalence of invertebrates found in the scats on the reserves compared with those collected on the farms. In addition, the relative energetic benefits of feeding from larger prey items (e.g. livestock) outweigh those of preying on smaller invertebrates which, although they may be high in energy content, would contribute considerably less energy due to their size. Thus, the optimality theory may explain the lack of invertebrates in the diet of farmland jackals (Pyke *et al.* 1977; Herbst & Mills 2010). Livestock hairs were an order of magnitude more common in the scats collected on the farms compared with those collected from the reserves. However, this also provides evidence to support the optimal hunting strategy of the black-backed jackal as livestock are readily available (abundant), easy to capture and high in energy content (MacArthur & Pianka 1966; Pyke *et al.* 1977; Herbst & Mills 2010).

These findings are similar to those described by Rowe-Rowe (1976) who reported significantly more grass (vegetation) and sheep wool (mammal hair) in the diet of farmland jackals compared with reserve jackals in KwaZulu-Natal. Bussiahn (1997) further reported that the diet of farmland jackals in the Eastern Cape was dominated by vegetation and mammal hair.

There was a distinct peak in the presence of livestock hair in the scats of farmland jackals during winter and a secondary peak in spring (Appendix A & B). These data are in agreement with the findings of Rowe-Rowe (1975) who documented peaks in sheep losses due to black-backed jackal predation in KwaZulu-Natal to occur during winter and spring. These peaks coincided with the two annual lambing seasons in late autumn and early spring (Rowe-Rowe 1975). This is also the case in the Eastern Cape where, although regional variations do occur, lambing seasons tend to take place during autumn and spring (Webber; Berrington *pers. comm.*).

The consumption of livestock by black-backed jackals during spring in this study may be attributed to higher energetic demands associated with its reproductive season during this period (Bernard & Stuart 1992; Klare *et al.* 2010). Generally, black-backed jackal pups are born during spring in the Eastern Cape (August-November) which, due to milk production, increases the demand for protein in the diet of the females. This may explain the increased consumption of livestock by black-backed jackals during the spring season (Rowe-Rowe 1975; Klare *et al.* 2010). In other seasons, jackals require less protein and therefore may shift their diet to other prey items that are more easily obtained e.g. fruit and seeds (Klare *et al.* 2010). The lambing seasons result in an increase in the availability of an accessible food resource for black-backed jackals and for those individuals not experiencing increased energetic demands due to the reproductive season, further explains their increased occurrence in the diet.

Impact on livestock

Black-backed jackal have long been considered vermin in South Africa due to their predilection for livestock (van der Merwe 1953a; Grafton 1965; Bothma 1971b; Rowe-Rowe 1975, 1976, 1983; Roberts 1986; Lawson 1989; Bussiahn 1997; Beinart 1998; van Sittert 1998; Loveridge & Nel 2004). The prevalence of livestock in the diet of jackal in this study is therefore not unexpected. However, the scat analysis method utilised here does not allow for enumerating the precise number of individuals consumed (Mills 1996) and is thus difficult to accurately quantify the damage. Discussions with both farmers (Webber & Berrington *pers. comm.*) indicated that stock losses due to predation range from 100 to 200 individuals (ratio of adults to young varies) per year translating to financial losses of between 50 000 and 200 000 ZAR, annually. However, black-backed jackals are not the sole predators responsible for this as caracals are also known to prey on livestock in the Eastern Cape (Bussiahn 1997).

Interestingly, Dorper sheep wool was recorded in one of the scats from Shamwari. This may indicate that black-backed jackals are roaming between the protected conservation area and the neighbouring farmlands. Similar findings were reported by Rowe-Rowe (1975) who documented sheep remains in a small portion of jackal stomachs from a reserve in KwaZulu-Natal. Rowe-Rowe (1983) also documented the presence of livestock in the diet of black-backed jackals on the Giants Castle Game Reserve (KwaZulu-Natal). Both Rowe-Rowe (1975) and Rowe-Rowe (1983) hypothesised the livestock had been eaten by the jackals whilst on feeding forays on neighbouring farmlands before returning to the reserves.

Although the fencing quality at Shamwari meets the nationally required standards for enclosing predators (O'Brien 2004), black-backed jackals have the ability to either burrow beneath fences or utilise holes created by other animals to move across fence lines (Heard & Stephenson 1987; Skinner & Chimimba 2005). As black-backed jackals are known to occur outside of protected areas (Kaunda & Skinner 2003; Walton & Joly 2003; Loveridge & Nel 2004; Skinner & Chimimba 2005), the possibility of jackals moving from farmlands onto reserves is also plausible, especially when attempting to escape persecution. The possibility of movement between reserves and farmlands by black-backed jackals highlights the importance of cooperation between land-owners in maintaining fence lines to reduce this movement, especially when this movement results in livestock being preyed upon (Woodroffe *et al.* 2005b).

Livestock depredation is one of the greatest sources of human-wildlife conflict globally (Sillero-Zubiri & Laurenson 2001; Thirgood *et al.* 2005; Woodroffe *et al.* 2005a and references therein) and has been documented for a wide variety of predators including certain felids (Oli *et al.* 1994; Linnel *et al.* 2001; Foster *et al.* 2010a), other generalist canids (Meriggi & Lovari 1996; Windberg *et al.* 1997; Knowlton *et al.* 1999; Rasmussen 1999) and other jackal species (Yom-Tov *et al.* 1995; Lanszki *et al.* 2006; Giannatos *et al.* 2009). Specifically, the movement of predators from conservation areas onto neighbouring farmland to prey on livestock has also been documented for other predators including the gray wolf (Meriggi & Lovari 1996), leopards (Kolowski *et al.* 2006; Balme *et al.* 2010), lions (Patterson *et al.* 2004; Holmern *et al.* 2007) and the snow leopard *Uncia uncia* (Oli *et al.* 1994; Bagchi & Mischra 2006).

A number of factors have contributed to these situations including domestic animals no longer exhibiting effective anti-predator behaviour, making them particularly vulnerable to predation (Kruuk 1972b). Furthermore, livestock may compete with wild herbivores for resources and reduce the abundance of wild prey for carnivores forcing them to feed on livestock as opposed to their natural prey (Sillero-Zubri & Laurenson 2001). Lastly, particularly in areas where agriculture is sufficiently developed, such as the Eastern Cape, there have been changes in the livestock husbandry techniques such that livestock are no longer extensively guarded by people or dogs and are thus easy prey for re-colonising carnivores (Breitenmoster *et al.* 2005; Linnel *et al.* 2005). In multiple-use landscapes where the conservation of wildlife occurs alongside agricultural activities, the issue of managing the black-backed jackal becomes increasingly complex when attempting to address the needs of the farmer and the wildlife manager and trying to conserve the species. This is further exacerbated by the lack of confidently being able to contain the predator on the reserves or keeping the predator off the farmlands (Thirgood *et al.* 2005; Woodroffe *et al.* 2005a).

Methodological critique

Recent research by Klare *et al.* (2011) has highlighted a number of important issues to consider when quantifying the diet of predators using scat analysis. A broad review of scat analysis methods indicated that the best approximation of the true diet of a carnivore is obtained by using biomass calculation models based on feeding trials (Klare *et al.* 2011). This approach indicates the relative importance of each dietary item (biomass) and thus provides both an ecologically and biologically more meaningful value than frequency of occurrence (Ciucci *et al.* 1996; Lanszki *et al.* 2006; Klare *et al.* 2011). Although ≥ 90 % of 50 peer-reviewed papers have described carnivore diet using the qualitative measure of frequency of occurrence, according to Klare *et al.* (2011) this is the least accurate way to assess carnivore diet. This is due to the method overestimating the importance of small food items eaten frequently and underestimating the importance of larger food items in the diet (Corbett 1989; Reynolds & Aebischer 1991; Weaver 1993; Ciucci *et al.* 1996; Mills 1996; Zabala & Zuberogoitia 2003; Klare *et al.* 2011). Moreover, this approach differs primarily from the quantitative methods (biomass calculations, and volume/mass measurements) by measuring how often food items are consumed and not the amount consumed. Thus, it cannot provide information about the relative importance of each prey item in the diet of a predator (Corbett 1989; Ciucci *et al.* 1996; Zabala & Zuberogoitia 2003; Klare *et al.* 2011).

The advantages of the qualitative approach, however, include being able to describe the full dietary spectrum of a predator ensuring rare dietary items are recorded (often overlooked by other methods) and allowing for easy comparisons with other dietary studies to be drawn (Corbett 1989; Reynolds & Aebischer 1991; Glen & Dickman 2006; Klare *et al.* 2011). Moreover, this approach is easy to conduct and relatively little time is spent extracting the information from the scats compared with the more time-consuming measuring of the volume/mass of different prey items, or the application of biomass models (Corbett 1989; Glen & Dickman 2006; Klare *et al.* 2011). Previous studies have indicated that the qualitative measure of frequency of occurrence is adequate for describing the diet of certain predators including the dingo, (Corbett 1989), the gray wolf (Ciucci *et al.* 1996), the spotted-tailed quoll *Dasyurus maculatus* (Glen & Dickman 2006) and the wolverine, *Gulo gulo* (van Dijk *et al.* 2007). However, the use of a combination of qualitative and quantitative methods (i.e. biomass models and frequency of occurrence) was determined by Ciucci *et al.* (1996), Zabala & Zuberogoitia (2003) and Klare *et al*. (2011) to be the best approach for describing carnivore trophic habits. This combined approach allows for the frequency of food items to be recorded in the diet and their relative importance to be understood (Ciucci *et al.* 1996; Zabala & Zuberogoitia 2003; Klare *et al*. 2011).

Selecting an appropriate analytical approach in accordance with the aim of the research is critical for ensuring the research objectives are achieved (Ciucci *et al.* 1996; Klare *et al.* 2011). If the objective is to describe the relative importance of each food item, then calculating biomass is the most appropriate method (Corbett 1989; Ciucci *et al.* 1996; Zabala & Zuberogoitia 2003; Klare *et al*. 2011). However, the aim of this study was to qualitatively determine and describe the dietary composition of the black-backed jackal in the Eastern Cape across two contrasting land-use types. Thus, utilising the qualitative method, frequency of occurrence, was appropriate for addressing the question (Corbett 1989; Ciucci *et al.* 1996; Glen & Dickman 2006).

Conclusion

The diet of black-backed jackal in the Eastern Cape is influenced by both season and land-use type. These factors affect the spatio-temporal variation of their prey availability and due to their generalist habits they will prey upon those food items that are most abundant, most obtainable and provide the most energy gain irrelevant of season or land-use type. Future research should quantitatively assess the diet of black-backed jackals in this region to compliment the dietary description of this study. This approach would also allow for the quantification of certain individual prey items. This information would be valuable to both wildlife managers and farmers when attempting to determine, for example, the number of individual ungulates or livestock consumed by black-backed jackals. Furthering our knowledge of black-backed jackal trophic biology in this way will allow for improved management of the species on both land-use types and improved conservation measures in a multiple-use landscape such as the Eastern Cape.

CHAPTER 4

THE VALIDATION OF *HairSnap* AS A NEW ANALYTICAL METHOD FOR MAMMALIAN HAIR IDENTIFICATION

4.1 INTRODUCTION

The use of hair morphology for identification is important in the fields of forensics (De Boom & Dreyer 1953; Verma *et al.* 2002), the identification of mammal species (Perrin & Campbell 1980; Keogh 1983, 1985; Cavia *et al.* 2008; Sahajpal *et al.* 2008; Sessions *et al.* 2009), wildlife ecology and mammal diversity surveys (Brunner & Triggs 2004), and predator feeding habits (Rowe-Rowe 1983; Hiscocks & Perrin 1987; Capitani *et al.* 2004; Breuer 2005; Glen & Dickman 2006; Marucco *et al.* 2008; Giannatos *et al.* 2009; Liu *et al.* 2010; Klare *et al.* 2010). For predator dietary studies, hair identification is particularly useful for quantifying the mammalian species consumed (Kruuk 1972a; Kruger *et al.* 1999; Ott *et al.* 2007; Wegge *et al.* 2009).

Several manual photographic reference collections and dichotomous keys have been developed to assist researchers in identifying mammalian species based on hair morphology (Brunner & Coman 1974; Perrin & Campbell 1980; Keogh 1983, 1985; Teerink 1991). However, this approach is often time-consuming and requires a trained individual to carry out the identification (Meyer *et al.* 1997; Meyer *et al.* 2002; Foster *et al.* 2010b). Moore (1988) further emphasised that a considerable amount of experience is necessary to identify mammal hairs with sufficient confidence. Variations in hair structure along their length and different hair types on the same individual (e.g. guard hair, vibrissae etc.) also present difficulties for manual identification (Keogh 1983, 1985; Oli 1993; Wallis 1993; Meyer *et al.* 1997). Most importantly, the method suffers from the subjectivity introduced by its reliance on an individual's interpretation of the hair's morphology rather than relying on quantitative mathematical measures (Verma *et al.* 2002).

Automated pattern recognition systems offer quantitative measures that are less subjective than manual pattern recognition through the application of a numerical or statistical analysis (Verma *et al.* 2002). These systems typically mirror the five basic design steps required for developing a generic classification system (Figure 4.1; Theodoridis & Koutroumbas 2003). The 'sensor phase' is concerned with the input and pre-processing of raw pattern images. This stage considers the rotation and scale of the pattern during image capture (Moyo *et al.* 2006). It is important that the orientation of the hair is consistent such that the direction of all the cuticular patterns point in the same direction. In addition, images must be of a standard size before being processed to avoid scaling variations and to ensure that the extraction of features occurs from the same number of pixels (Moyo *et al.* 2006). The 'feature generation' phase deals with the extraction of numerical measurements; a set of which is referred to as a feature vector (Moyo *et al.* 2006). For example, the average distance between the ridges forming the pattern of a fingerprint is termed a feature vector (Ross *et al.* 2003). The 'feature selection' stage involves the selection of the unique information, key to identifying that specific pattern. This process extracts the information contained in the image and provides a representation of the local (variation of the pattern in the image) and global variations (overall average variation of the pattern across all samples) in the pattern (Moyo *et al.* 2006). 'Classifier design' entails implementing mechanisms that place patterns in their correct classes or training sets (Theodoridis & Koutroumbas 2003) and the final 'system evaluation' stage determines the optimal performance of the system (Moyo *et al.* 2006).

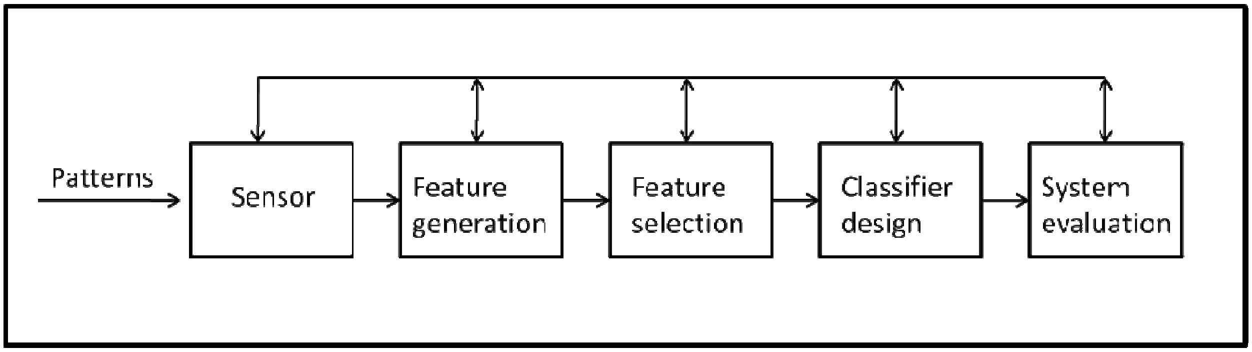

Figure 4.1: The five steps for designing a classification system (taken from Theodoridis & Koutroumbas 2003).

Principal reasons for distinguishing between individuals of various species are to investigate their demographics, life histories, and for behavioural and ecological studies (Hammond *et al.* 1990; Wells *et al.* 1999; Stevick *et al.* 2001; Speed *et al.* 2007). To this end, automated pattern recognition systems have been used to differentiate what appears to be two broad categories of patterns including the morphological shapes of certain anatomical features (e.g. fin and fluke shapes) and the body marking patterns of animals (e.g. spots or stripes) from both aquatic and terrestrial environments. Distinction between individuals of a species utilising fin or fluke shapes (morphological features) has been undertaken for great white sharks *Carcharodon* *carcharias* (Anderson & Goldman 1996), nurse sharks *Ginglymostoma cirratum* (Castro & Rosa 2005), and blue whales *Balaenoptera musculus* (Sears *et al.* 1990). Differentiation between individual animals utilising body marking patterns has been performed for a number of species including tigers *Panthera tigris* (Karanth & Nichols 1998), leopards *Panthera pardus kotiya* (Miththapala *et al.* 1989), servals *Leptailurus serval* (Geertsema 1985), snow leopards (Jackson *et al.* 2006) and whale sharks *Rhincodon typus* (Arzoumanian *et al.* 2005).

Of the applications of automated pattern recognition systems for vertebrates, the research has been dominated by studies differentiating individual marine organisms; particularly cetaceans (whales, dolphins and porpoises) and elasmobranchs (sharks, skates and rays) (Hammond *et al.* 1990; Araabi *et al.* 2000). The growth in size of photo-catalogues of these marine species reached a point where the datasets were too large for manual identification of individuals, resulting in the application and development of automated pattern recognition systems (Araabi *et al.* 2000; Arzoumanian *et al.* 2005; Beekmans *et al.* 2005; van Tienhoven *et al.* 2007). Comparatively few studies, aimed at identifying individuals of a species using automated pattern recognition systems, have been conducted in the terrestrial environment (Kelly 2001; Gamble *et al.* 2008; Anderson *et al.* 2010). However, automated pattern recognition systems have been successfully employed for humans (Verma *et al.* 2002; Ross *et al.* 2003; Sanchez-Avila & Sanchez-Reillo 2005) where biometric indicators differentiate between individuals mostly for forensic purposes but also to control access to secured areas (Sanchez-Avila & Sanchez-Reillo 2005).

Despite evidence to support the automation of the pattern recognising process through the successful and effective application of quantitative measures to differentiate individuals (Speed *et al.* 2007); the approach has not been widely employed in predator diet assessments. This is mostly due to the process being highly technical, specialised and only targeting particular taxa or unique morphological features of certain species (Speed *et al.* 2007). Furthermore, almost all studies that have employed automated pattern recognition systems have sought to determine intra-species variation (Araabi *et al.* 2000; Kelly 2001; Arzoumanian *et al.* 2005; Beekmans *et al.* 2005; van Tienhoven *et al.* 2007; Gamble *et al.* 2008; Anderson *et al.* 2010). Very little research exists for determining inter-species variation (Meyer *et al.* 1997; She *et al.* 2001; Brunner & Triggs 2004; Moyo *et al.* 2006; Foster *et al.* 2010b) which is considerably more relevant for ecological studies like carnivore diet assessments (Eloff 1984; Stuart & Hickman 1991; Hayward *et al.* 2006b; Bissett & Bernard 2007; Rapson & Bernard 2007; Kruger *et al.* 1999; van der Merwe *et al.* 2009; Martins *et al.* 2010).

Moyo *et al.* (2006) was the first study to apply automated pattern recognition techniques to the classification of African mammalian species using hair-scale cuticular patterns. *HairSnap*, for the public domain graphics application, ImageJ (ImageJ 2005), was developed for this purpose (Moyo *et al.* 2006). Utilising five different mammal species (blue wildebeest *Connochaetes taurinus*, impala, black-backed jackal, springbok and zebra *Equus quagga*), *HairSnap* was trained with three images of hair-scale patterns per species to develop a reference library (Moyo *et al.* 2006). The programme was then tested with five ‘unknown’ images per species. The results from this initial study were encouraging. The overall accuracy of the programme was approximately 72 % and two species (black-backed jackal and blue wildebeest) were identified correctly 100 % of the time (Moyo *et al.* 2006). Subsequently, Foster *et al.* (2010b) improved the programme by adjusting the algorithm making it better suited for the task. Moreover, Foster *et al.* (2010b) predetermined the number of images of hairs from three ungulate species (springbok, zebra and impala) necessary to train *HairSnap* for accurate identification. The algorithm adjustment and change in approach improved the overall accuracy of *HairSnap* by approximately 25 % (Foster *et al.* 2010b). However, in both the studies by Moyo *et al.* (2006) and Foster *et al.* (2010b) the number of input species was small (≤ 5) and the results may therefore reflect the programmes ability to differentiate patterns within a small sample size (Moyo *et al.* 2006; Foster *et al.* 2010b). Thus, they concluded a larger number of test samples (species) are needed to verify the accuracy of the programme.

The aim of this study was to determine the accuracy of the automated pattern recognition programme, *HairSnap*, in identifying hairs from nine important prey species found in the diet of black-backed jackals.

4.2 MATERIALS AND METHODS

The validation of *HairSnap* was conducted on two levels; its efficiency and its accuracy. Efficiency was defined as the number of images needed to train the programme to accurately identify each species. Accuracy was defined as the number of times a species was correctly identified (Foster *et al.* 2010b).

Species selection and sample preparation

Nine mammal species were selected for the validation of *HairSnap* (bushbuck, greater kudu, common duiker, springhare, black-backed jackal, large-spotted genet *Genetta tigrina*, small-spotted genet *Genetta genetta* and striped polecat *Ictonyx striatus*). The selection of these species was based upon their occurrence in black-backed jackal diet across South Africa (Grafton 1965, Bothma 1971b, Rowe-Rowe 1983, Bussiahn 1997, Do Linh San *et al.* 2009, van der Merwe *et al.* 2009, Klare *et al.* 2010). These species represented three orders: Ruminantia, Carnivora and Rodentia.

Angora goats were included under the livestock category based on their presence in black-backed jackal scats in this study (*Chapter 3*). Initially, dorper sheep, scrub hare, rock hyrax *Procavia capensis* and common warthog were also included in the species selection. However, the dorper sheep wool was too fine for appropriate images to be captured. Although scrub hares are particularly prevalent in the diet of the black-backed jackals (Bothma 1971b; Rowe-Rowe 1983; Klare *et al.* 2010), their guard hairs demonstrate considerable variability along their length making it difficult to capture suitable images for the reference library (Perrin & Campbell 1980). The common warthog was also removed from the test set as their burrowing lifestyle and propensity for wallowing coats the hairs in mud (Skinner & Chimimba 2005). Despite numerous cleaning attempts using alcohol (30%) and sonication in an ultrasound bath (Sessions *et al.* 2009) it was not possible to discern the cuticular pattern of the hairs of this species. The rock hyrax was removed from the test set as the guard hairs of this species were particularly rounded which meant that suitably focussed images of the hair pattern were not possible (Perrin & Campbell 1980).

HairSnap requires the system to be populated with a training set for each species which acts as a reference library (Foster *et al.* 2010b). The reference library dataset was compiled from guard hairs collected from museum specimens held at the Amathole Museum (King Williams Town, Eastern Cape Province, South Africa). Guard hairs were selected because they are the most frequently used hair type in predator stomach content and faecal analyses (Perrin & Campbell 1980; Keogh 1983; Hiscocks & Perrin 1987; Quadros & Monteiro-Filho 1998; Spaulding *et al.* 2000; Arjo *et al.* 2002; De Marinis & Asprea 2006; Do Linh San *et al.* 2009; Liu *et al.* 2010). In addition, guard hairs were used by Moyo *et al.* (2006) and Foster *et al.* (2010b) when developing *HairSnap*.

Training set hairs were mounted on brass stubs with double-sided graphite tape and gold coated by a Bulzer's™ gold sputtering device (Sessions *et al.* 2009). The stubs were then placed in a Tescan Vega™ scanning electron microscope (SEM) at 30 kilovolts (KV) in accordance with the procedure described by Foster *et al.* (2010b). The training set images of the midpoint region were captured with the hair in a horizontal position at magnifications ranging from 1 000 to 2 500 times (Perrin & Campbell 1980; Teerink 1991; De Marinis & Asprea 2006; Moyo *et al*. 2006; Foster *et al.* 2010b). A rectangular region of interest (ROI) tool was then utilised to manually segment the scale pattern from each input image (Figure 4.2).

The training set for each species provides a dataset of feature vectors representing the hair scale patterns of that species (Moyo *et al*. 2006; Foster *et al.* 2010b). When *HairSnap* is tested with an unknown image, it returns a score based on a Euclidean distance measure between the unknown hair pattern and that of the training set's vector features (Ross *et al.* 2003; Foster *et al.* 2010b). The lower the score the more similar the unknown image is to a species in the reference library (Foster *et al.* 2010b).

In order to determine the optimal training set size (the number of images needed to populate the library to ensure accurate identification) for each species (Foster *et al.* 2010b), *HairSnap* was trained with 21 images of each species at successive intervals of one image at a time. *HairSnap* was tested with five replicate images of each species at each successive interval and the mean score (Euclidean distance) recorded. The optimal training set sample sizes for each species were determined when the recorded scores tapered off to within five percent of the minimum score (Figure 4.4; Foster *et al.* 2010b). The images captured for the testing of *HairSnap* were termed the test set sample. The test set sample comprised 10 images captured from 10 different hairs for each species. The images comprising the test set samples were taken from known species. Due to the photographs being captured at varying magnifications and the user having the ability to define the size of the ROI, scaling variations may occur (Moyo *et al.* 2006). However, this was mitigated for by restricting the ROI to the width of the hair (Moyo *et al.* 2006; Foster *et al.* 2010b). The ROI was further restricted to a width that was equal to or greater than its height (Foster *et al.* 2010b). This allowed for the size standardisation of scale pattern images (Moyo *et al.* 2006).

In order to determine the matching accuracy of *HairSnap*, the test set samples (10 images per species) were tested against the optimal training set for each of the nine species (Foster *et al.*

2010b). A standardised ROI size was utilised to ensure consistent scale pattern areas were selected for identification (Moyo *et al.* 2006; Foster *et al.* 2010b). *HairSnap* returned a list of possible matches in order of the best match (lowest score) to the most dissimilar (highest score) for each test set image pattern. Only if the correct species was listed in first place was it regarded as a match (Foster *et al.* 2010b).

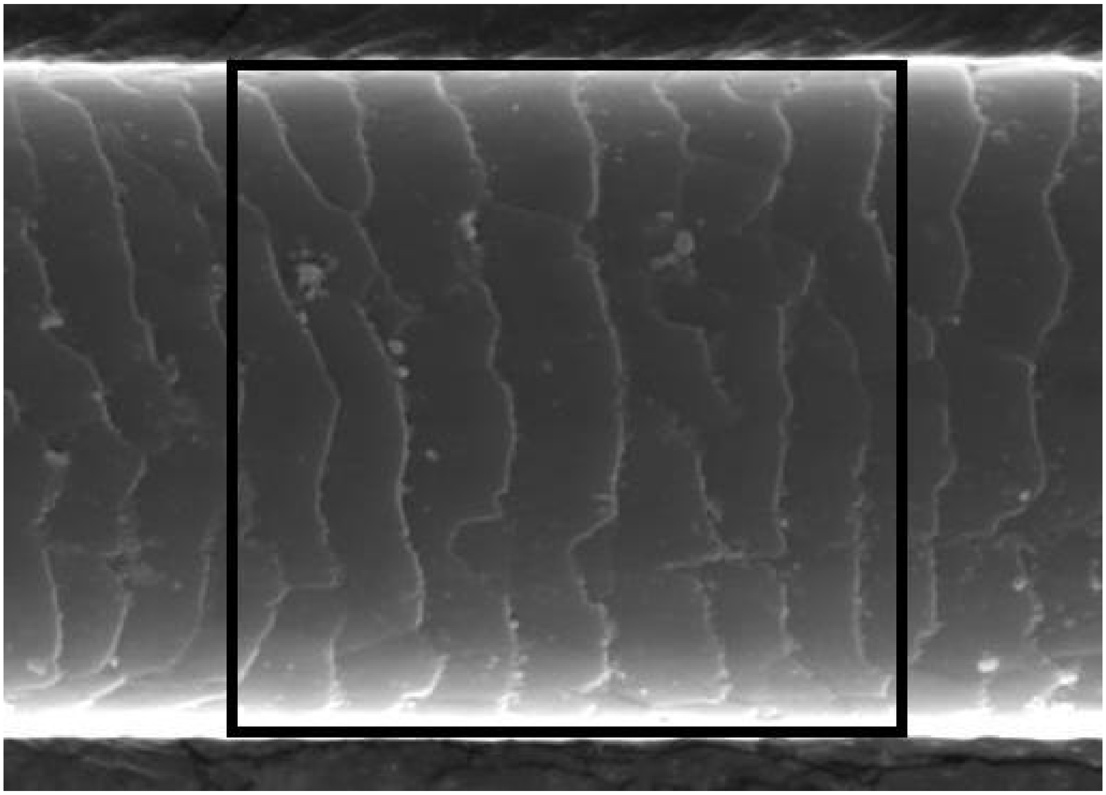

Figure 4.2: Input micrograph (common duiker) with the region of interest (ROI) selected to segment the scale pattern from the background image.

Data analysis

Efficiency of HairSnap

The efficiency test produced the number of images necessary to train *HairSnap* for each species. These were compared among species such that the lower the number of images needed to train the programme for a particular species; the more efficient *HairSnap* was at capturing the unique feature vectors defining that species. The overall efficiency of *HairSnap* was calculated by determining the mean (± SD) number of images needed to train the programme across all species.

Accuracy of HairSnap

HairSnap produced a list of ranked scores linked to a species in order of most similar (lowest score) to most dissimilar (highest score) when tested with an 'unknown' pattern for each species (Moyo *et al.* 2006; Foster *et al.* 2010b). The accuracy of identification per species was determined by summing the number of correct identifications (a match in first place) and converted to a percentage. The overall accuracy of *HairSnap* was calculated by determining a mean (± SD) of the percentage accuracies from each species.

4.3 RESULTS

Efficiency of HairSnap

The overall efficiency of *HairSnap,* measured by the mean minimum number of images needed to train the programme across all species, was 19 images (Table 4.1). However, *HairSnap* was most efficiently trained using Angora goat hair with only 16 images being necessary (Table 4.1). Similarly, common duiker also required relatively few (17) images. Bushbuck and greater kudu needed 20 images respectively for accurate identification. *HairSnap* was less efficient for black-backed jackal, springhare and striped polecat each of which required 21 training images for accurate identification (Figure 4.4).

As the number of images trained by *HairSnap* increased when determining the optimal training set size, the variation around the mean match score decreased for bushbuck, large-spotted genet and springhare (Figure 4.4). This can be attributed to these species having unique feature vectors which are easily distinguishable by *HairSnap*. By contrast, as the number of images of Angora goat, black-backed jackal, common duiker and striped polecat hair trained by *HairSnap* increased, the variation around the mean match score remained relatively uniform (Figure 4.4). In these instances, *HairSnap* was not capable of detecting the full extent of the feature vectors defining these species resulting in similar levels of variation around the mean with each additional reference image trained. The smallest variation around the mean match score as the number of images trained increased was exhibited by Greater kudu. The pattern for this species must therefore have been particularly unique and the feature vectors easy to distinguish by *HairSnap*. Small-spotted genet expressed the largest variation around the mean indicating the programme was not capable of effectively capturing the feature vectors of this pattern irrelevant of the number of images trained (Figure 4.4).

Accuracy of HairSnap

The overall accuracy of *HairSnap* was 38 % (Table 4.1). *HairSnap* was most accurate at identifying black-backed jackal (80 %) and least accurate at identifying large-spotted genet (0 %; Figure 4.3). Three species were accurately identified over 50 % of the time including black-backed jackal, greater kudu and striped polecat (Figure 4.3). Greater kudu and striped polecat were confused with one other species (Table 4.1). Common duiker, large- and small-spotted genet, and springhare were confused with four other species (Table 4.1). *HairSnap* struggled to differentiate bushbuck classifying it as either common duiker or striped polecat. Angora goat was mis-matched as black-backed jackal or small-spotted genet, and black-backed jackal was confused with Angora goat and Greater kudu (Table 4.1).

An average of three different species occupied position one (other than the species in question) when attempting to identify each of the nine species (Table 4.1). The most frequent species to be confused with another species were black-backed jackal and Greater kudu. They incorrectly occurred in position one for 5 of the 8 other species respectively (Table 4.1).

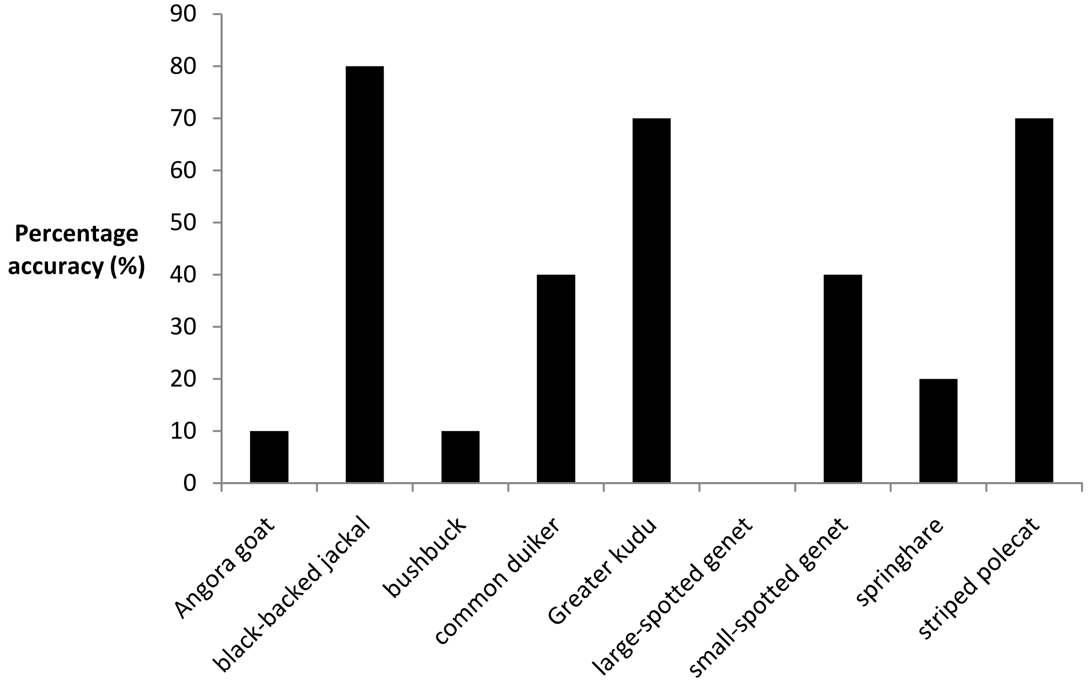

Figure 4.3: The percentage accuracy (%) of *HairSnap* at identifying each of the nine mammal species.

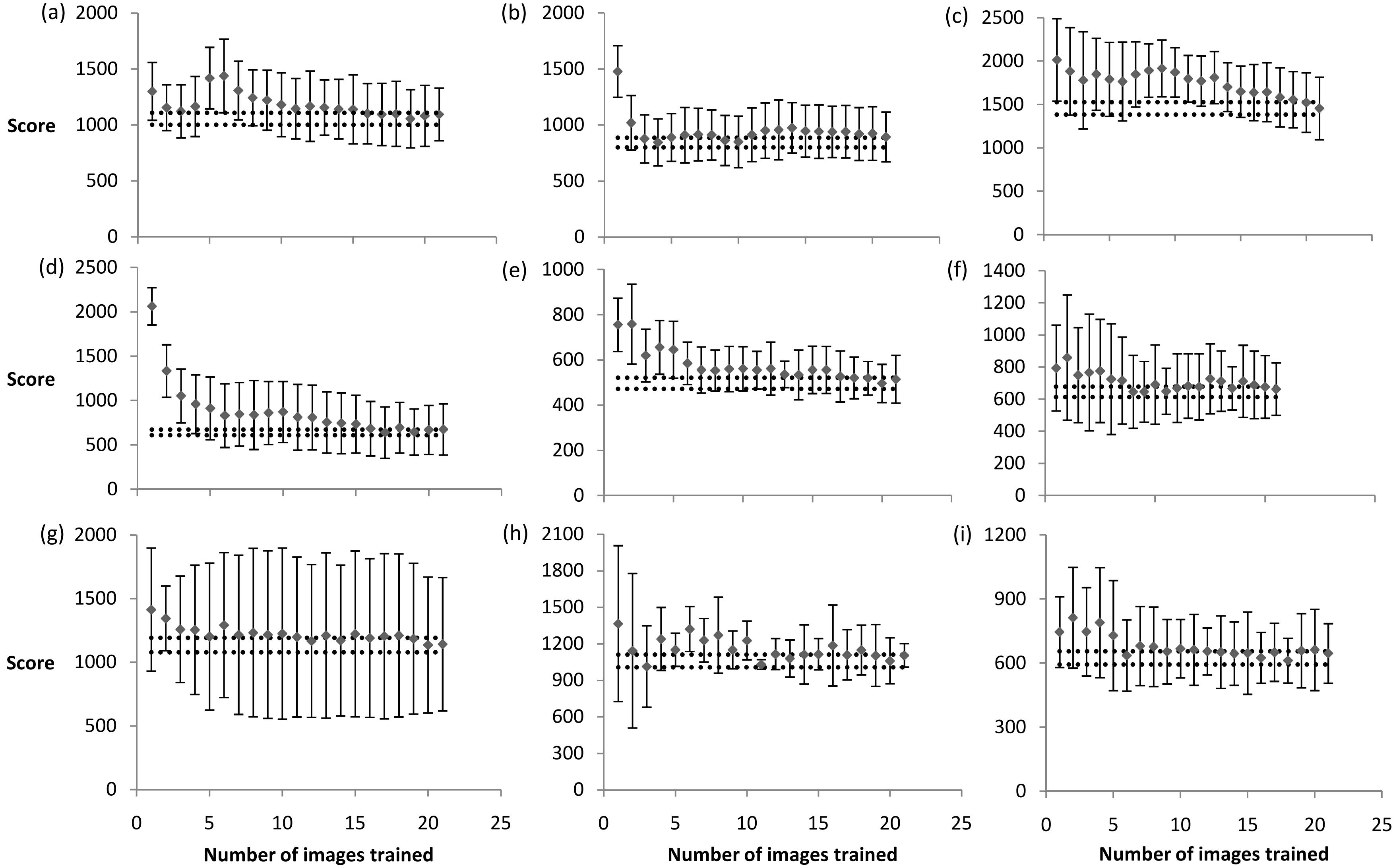

Figure 4.4: The optimal training set sizes for each of the nine mammal species; (a) Angora goat, (b) black-backed jackal, (c) bushbuck, (d) common duiker, (e) Greater kudu, (f) large-spotted genet, (g) small-spotted genet, (h) springhare and (i) striped polecat. Vertical bars indicated standard deviations. Dotted lines indicate 5 % of the minimum score.

Table 4.1: A summary table showing the efficiency, accuracy (%) of identification, the number and names of the species incorrectly matched, and the number of other species a species was incorrectly identified as.

Species	**Efficiency (number of images trained)**	**Accuracy (%)**	**Number and names of species incorrectly matched**	**Number of other species it was incorrectly identified as**
Angora goat	16	10	2; black-backed jackal, small-spotted genet	2
black-backed jackal	21	80	2; Angora goat, Greater kudu	5
bushbuck	20	10	2; common duiker, striped polecat	0
common duiker	17	40	4; black-backed jackal, Greater kudu, springhare, striped polecat	2
Greater kudu	20	70	1; black-backed jackal	5
large-spotted genet	19	0	4; black-backed jackal, Greater kudu, small-spotted genet, striped polecat	2
small-spotted genet	19	40	4; Angora goat, black-backed jackal, large-spotted genet, springhare,	2
springhare	21	20	4; common duiker, Greater kudu, large-spotted genet, striped polecat	2
striped polecat	21	70	1; Greater kudu	4
Mean (± SD)	**19.3 ± 1.8**	**37.8 ± 29.9 %**	**2.7 ± 1.3**	**2.7 ± 1.7**

4.4 DISCUSSION

The primary advantage of automated pattern recognition systems is the removal of observer subjectivity in the identification of patterns (Verma *et al.* 2002; Theodoridis & Koutroumbas 2003). However, such systems also need to accurately identify patterns with a statistical confidence of at least 95 % to make them worthwhile (Hampton 2003). The aim of *HairSnap* is to accurately differentiate between species using their cuticular hair-scale patterns by applying a quantitative mathematical measure (Euclidean distance) (Moyo *et al.* 2006; Foster *et al.* 2010b). The overall accuracy of identification of *HairSnap* in this study was 38 %. This is considerably lower than the previous testing of *HairSnap* by Moyo *et al.* (2006) and Foster *et al.* (2010b) who determined overall accuracies of 72 and 97 % respectively. Factors explaining the decrease in accuracy may include image quality (Bateson 1977; Agler 1992; Anderson *et al.* 2007), sample size and species composition of the sample.

Image quality

Image quality is known to affect the accuracy of identification of animal patterns (Friday *et al.* 2000; Arzoumanian *et al.* 2005; Sanchez-Avila & Sanchez-Reillo 2005; Jackson *et al.* 2006; Gamble *et al.* 2008). Higher quality photographs can produce higher similarity coefficients (Kelly 2001), reduced error rates in image pattern identification (Stevick *et al.* 2001) and decrease the probability of not finding a true match when there is one (Beekmans *et al.* 2005). Poor focus and clarity, and low-resolution images all contribute to a decline in the accuracy of identification of animal patterns. The images used in this study were of a much better quality than those used previously for *HairSnap* (Foster, *pers. comm.*). Thus it is not likely that image quality contributed to the poor accuracy measure in this study.

Sample size

An increase in the number of species in the reference library (sample size) appears to be linked to a decline in the accuracy of identification of *HairSnap*. This is evident when comparing the lower overall measure of accuracy (72 %) of Moyo *et al.* (2006) who tested *HairSnap* with five species with Foster *et al.* (2010b) who tested *HairSnap* with three species and recorded an accuracy measure of 97 %. Thus *HairSnap* may not be capable of processing large samples resulting in the decreased levels of accuracy observed in this study. However, Brunner & Triggs (2004) developed the programme, *Hair ID,* and were able to successfully populate a reference library with over 100 samples and still retain reliable levels of accuracy (Brunner & Triggs 2004). However, it is important to note that *Hair ID* is not a fully automated system comparable with *HairSnap* as users of the programme are required to manually enter the characteristics of their unknown samples (e.g. cross-section shape) prior to selecting a possible match. Thus, the continued human involvement in the decision and, in essence, the selection of a match from an electronic catalogue as opposed to a physical one (reference collection) may have permitted the considerably larger sample size reported. Importantly, no other studies investigating inter-species variation have been conducted with a sample size of species competitive with this study.

Species composition

It is suggested that the species composition of the test set influences the accuracy of identification of *HairSnap*. For example, if the test set sample comprises patterns which are all very similar there is the possibility *HairSnap* will not be able to differentiate all of them with reliable accuracy. If the test set sample contains patterns which are all unique and considerably different from one another, *HairSnap* may be able to distinguish these patterns with greater accuracy. This is evident when comparing the measures of accuracy of the same species utilised in the studies by Moyo *et al.* (2006) and Foster *et al.* (2010b) which had differing species comprise their test set samples. The test set sample used by Moyo *et al.* (2006) comprised three species (springbok, zebra and impala) used by Foster *et al.* (2010b) and two additional species (blue wildebeest, black-backed jackal). A decrease in the accuracy of identification of up to 60 % was observed when comparing the accuracy measures for the three overlapping species tested. Thus, it would appear the additional patterns (species) in the test set influenced the accuracy of identification of *HairSnap*. Furthermore, upon inspecting the patterns of the two additional species in the test set used by Moyo *et al.* (2006), they were considerably similar to the initial three species which may have led to increased difficulties for the programme when capturing the distinguishing features resulting in the decline in accuracy.

The species composition of the test set sample in this study differed greatly from the study by Moyo *et al.* (2006) and overlapped with one species only, the black-backed jackal. When comparing the reported accuracy of identification of black-backed jackal in this study with that of Moyo *et al.* (2006) an increase from 80 to 100 % is observed. Examining the patterns of the species comprising the test set sample in the study by Moyo *et al.* (2006), indicated the patterns were not extremely similar. However, observing the patterns comprising the test set sample in this study indicated they were noticeably similar. This supports the suggestion that the patterns (species) constituting the test set sample in this study contributed to a decline in the measure of accuracy.

Optimal training set sample size

When comparing the number of training images necessary to ensure accurate identification of patterns, She *et al.* (2001) required 22 and 38 samples of merino sheep wool and Angora goat mohair respectively. From each of the nine subjects in the study by Verma et al. (2002), 25 images were necessary. By contrast, van Tienhoven *et al.* (2007) utilised considerably fewer reference images (between one and three) of spotted ragged-tooth shark *Carcharias taurus* to maintain an accuracy of identification of between 72 and 92 %. However, this was restricted by the lack of more reference images being available for the individuals in the dataset. Sanchez-Avila & Sanchez-Reillo (2005) applied populated their reference collection with 60 images for each of 50 subjects when conducting human iris recognition tests. According to van Tienhoven *et al.* (2007), the greater the number of reference images against which comparisons can be made, the higher the accuracy of the system. This was supported by Arzoumanian *et al.* (2005) who noted that as the size of an image database increases so the accuracy of identification increases.

The average number of images (19) per species needed to train *HairSnap* was considerably lower than that needed for mohair by She *et al.* (2001) and was comparable with the studies by Verma *et al.* (2002) and Sanchez-Avila & Sanchez-Reillo (2005) respectively. However, it was considerably higher than the studies by Arzoumanian *et al.* (2005) and van Tienhoven *et al.* (2007). Foster *et al.* (2010b) reported a mean training set size of 12 images per species which is lower than this study. However, as the test set sample in this study is larger and differs in species composition from the study by Foster *et al.* (2010b), a true comparison is difficult to draw. Furthermore, this study has investigated inter-species variation and comparisons with studies reporting on intra-species variation may also be inaccurate.

According to van Tienhoven *et al.* (2007), the number of training images necessary for accurate identification can be restricted by the availability of images for the study or statistically pre-determined if images are readily available (Foster *et al.* 2010b). However, the higher the number of reference images populating a dataset does result in raised levels of accuracy and should be acknowledged when attempting to achieve increased levels of accuracy (Arzoumanian *et al.* 2005; van Tienhoven *et al.* 2007; Foster *et al.* 2010b).

***Efficiency of* HairSnap**

The varied number of images necessary to develop optimal training sets for each species in this study indicated that *HairSnap* appeared to be more efficient at capturing the necessary feature vectors of certain species (e.g. Angora goat, common duiker) and less efficient for others (e.g. black-backed jackal, striped polecat and springhare). This was to be expected as examining the scale patterns of the former two species (Angora goat, common duiker) with the naked eye showed they are quite unique thus making it easier for *HairSnap* to capture their defining feature vectors (Figure 4.5). Moreover, the scale patterns of the three latter species (black-backed jackal, striped polecat and springhare) were particularly similar and thus *HairSnap* may need more images to adequately capture their defining characteristics (Figure 4.5). *HairSnap* in the present study was less efficient at capturing the necessary information (mean of 19 images needed per species) from the test set sample compared with the study by Foster *et al.* (2010b) who needed a mean of 12 images per species.

However, although *HairSnap* may be more efficient at capturing feature vectors from certain species by utilising fewer images, it may be identifying these same species less accurately. This highlights an evident trade-off between efficiency and accuracy. For example, although *HairSnap* was more efficient at capturing feature vectors from the Angora goat and common duiker images (16 and 17 images respectively); they were identified with accuracies of 10 and 40 % respectively. Thus, it may be better to train *HairSnap* with more reference images to ensure sufficient feature vectors are captured and the measure of accuracy is increased. However, this may result in increased labour and time costs. Future work utilising this programme would need to consider this. Moreover, the measurement of efficiency of *HairSnap* may need to incorporate the accuracy measure in order to obtain a more valuable measure of efficiency for the programme.

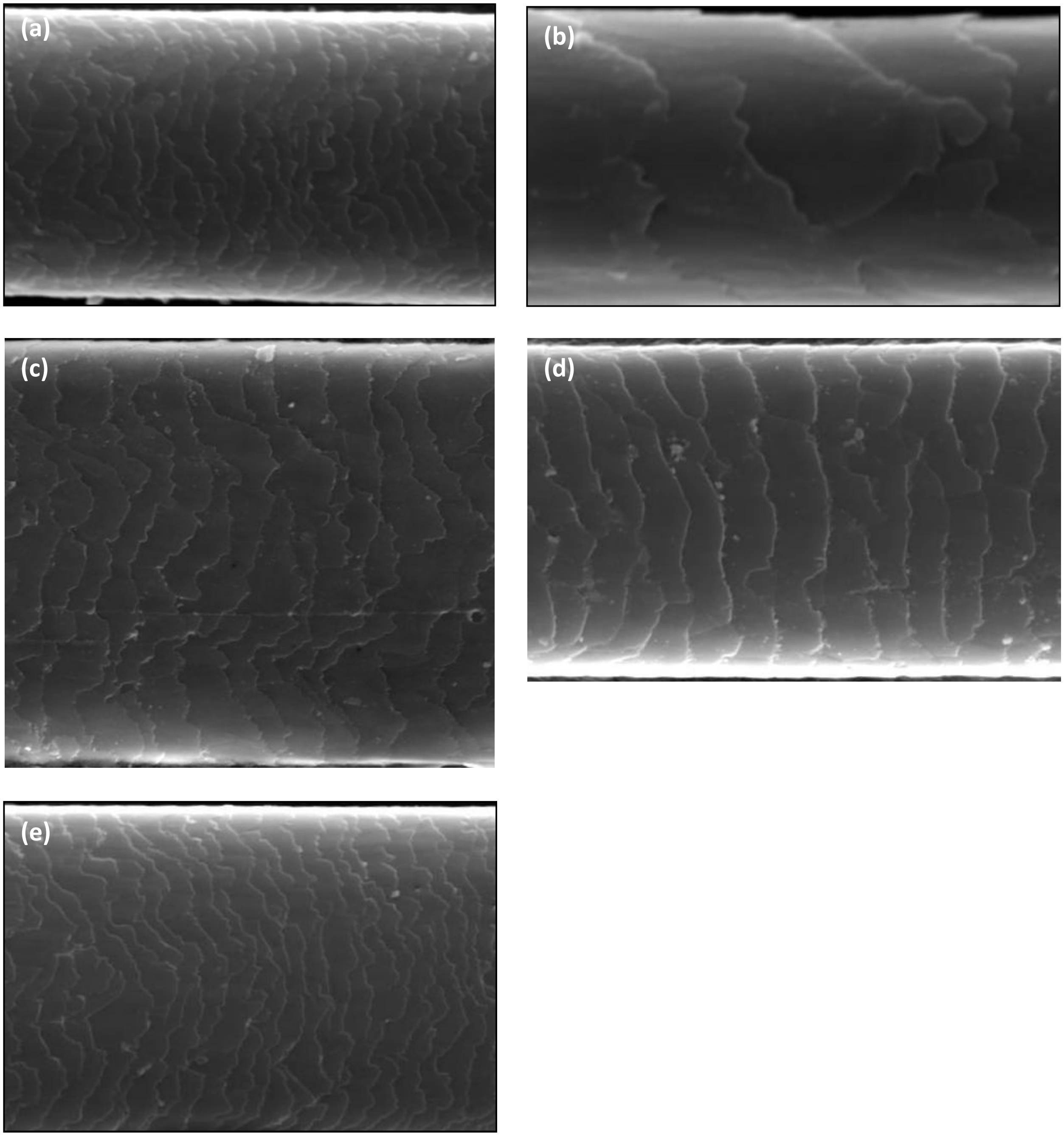

Figure 4.5: Scanning electron microscope (SEM) micrographs of cuticular hair-scale patterns of (a) black-backed jackal, (b) Angora goat, (c) springhare, (d) common duiker, and (e) striped polecat.

Comparison with other automated pattern recognition systems

Arzoumanian *et al.* (2005) and van Tienhoven *et al.* (2007) used the interactive individual identification software (Interactive Individual Identification Software 2004) programme to identify whale sharks and spotted ragged-tooth sharks with accuracies of 72 and 92 % respectively. Other studies on marine vertebrates have reported accuracies of identification of between 93 and 97 % when identifying dolphins (Araabi *et al.* 2000) and sperm whales (Beekmans *et al.* 2005). Significantly, Beekmans *et al.* (2005) compared two methods of identification, the Highlight method (Whitehead 1990) and the Europhlukes method (Huele *et al.* 2000) and reported high (84-88 %) accuracies for each, but achieved even higher accuracy (97 %) when combining the two. This is similar to Ross *et al.* (2003) who utilised a hybrid fingerprint matching technique combining minutiae (the major features of a fingerprint; Jiang & Yau 2000; Luo *et al.* 2000; Jain *et al.* 2001; He *et al.* 2003) with a fingerprint ridge feature map to increase the level of accuracy of identification. This indicates that the combined use of two different pattern recognising methods may increase the accuracy measure to more acceptable levels.

Gamble *et al.* (2008) reported an accuracy of identification of between 95 and 98 % for marbled salamanders *Ambystoma opacum* which is significantly higher than that achieved in this study. Notably, Gamble *et al.* (2008) developed a new algorithm that assesses attributes of a patterned surface at multiple resolutions; a numerical representation of which (standard to most algorithms) is then compared with other images. The algorithm ranks all the images in the database against each other by level of visual similarity. According to the authors, this approach has two significant advantages; improving the recognition performance substantially; and extending the reach of pattern recognising algorithms to a greater variety of patterned organisms (Gamble *et al.* 2008). Future work using *HairSnap* may consider the application of this algorithm in place of the Euclidean distance to improve its accuracy.

The use of the Euclidean distance measure by Ross *et al.* (2003) to differentiate individual fingerprints was effective at ensuring an accuracy of over 90 %. However, the comparison of three different distance measures by Sanchez-Avila & Sanchez-Reillo (2005) including the Euclidean distance, the binary Hamming distance and a dissimilarity distance function, indicated that the binary Hamming distance measure was the best suited measure for ensuring the highest accuracy of identification for human iris recognition. Trialling a suite of different distance measures for *HairSnap* in this regard may improve its accuracy and should be considered in the future.

An integrated approach by She *et al.* (2001) employed non-linear demarcation functions of the scale patterns of goat mohair and merino sheep wool by using artificial neural networks. This was applied to the evaluation of the fibre quality and proved to be particularly successful (accuracy of 88 %). Although the approach needs to be validated with a larger sample size to ensure it can retain its accuracy, this too may be a more effective approach for the differentiation of mammalian hair-scale patterns.

Overall, it is difficult to compare the measure of accuracy of this study with most of the abovementioned research as most studies attempt to differentiate individuals of the same species (Arzoumanian *et al.* 2005; van Tienhoven *et al.* 2007) and not determine inter-species variation, their algorithms and/or distance measures are varied (She *et al.* 2001; Sanchez-Avila & Sanchez-Reillo 2005; Gamble *et al.* 2008), their sample sizes differed (She *et al.* 2001; Ross *et* *al.* 2003), and the pattern type utilised differed such that morphological shapes are utilised (Araabi *et al.* 2000; Beekmans *et al.* 2005) as opposed to body marking patterns which can be regarded as similar to hair-scale patterns. Thus, although the measure of accuracy in this study is poor, it would not be appropriate to compare it directly with the accuracy's in the abovementioned studies without appreciating the individuality of each study.

Comparison with manual pattern recognition techniques

Although *HairSnap* has great potential if its accuracy measure can be increased, there are also certain drawbacks to the method. For example, after the fieldwork has been carried out the researcher would need to return to the laboratory in order to process the samples, capture the hair images on a scanning electron microscope and utilise a computer to run the *HairSnap* programme. In this regard, the manual method may be more practical as transporting a light microscope, a dichotomous key and the necessary materials into the field is considerably easier. When comparing the relative costs and labour necessary to conduct each method, the use of light microscopy proved to be considerably more time-consuming (≈ 140 hours) than the *HairSnap* method (≈ 32 hours). Despite it taking longer, the method was relatively inexpensive (≈320 ZAR) costing approximately a quarter of the *HairSnap* method (≈1 200 ZAR). Although the accuracy of identification of the hair-scale cuticular pattern should not hinge upon the availability of resources, this is an important point to consider if resources are limiting.

A combination of hair characteristics

Although *HairSnap* was tested in this study using only hair-scale cuticular patterns to differentiate species, there is the possibility of improving the accuracy measure through the combined use of other hair characteristics e.g. medulla shape, cross section width, cortical width (Day 1966; Mukherjee *et al.* 1994; Meyer *et al.* 2002; Kuhn & Meyer 2010). Increasing the number of characteristics upon which the system makes a decision results in a more robust system that is more inclined to make more accurate identifications (Meyer *et al.* 2002). This was highlighted in the study by Kuhn & Meyer (2010) which successfully distinguished species of the lutrinae (Mustelidae, Carnivora) to genus level for all species and to species level for certain species based upon the combination of the macroscopic colour, the morphology and length, the microscopic cross-section, the medulla shape and the cuticle characteristics of their hair. Thus utilising a combination of hair characteristics may solve for the poor accuracy of *HairSnap* observed in this study.

Conclusion

HairSnap was not able to accurately differentiate among nine mammal species based on their hair-scale cuticular patterns in this study. However, the method has the ability to broaden the scale at which ecological studies and predator dietary assessments are conducted if its accuracy measure is to be improved (Arzoumanian *et al.* 2005; Gamble *et al.* 2008). For example, if a reference collection was to be developed for all mammals in the southern African subregion or sub-Saharan Africa, any researcher conducting ecological studies or predator dietary studies identifying mammals to species level (based on their hair-scale cuticular patterns) in these regions can utilise *HairSnap* with confidence and ease. Moreover, if resources are not a limiting factor, the use of the *HairSnap* method would reduce the time spent processing and identifying hairs considerably.

In order for *HairSnap* to reach its full potential, future studies should be aimed at implementing different algorithms or a combination of algorithms to increase the accuracy measure. Furthermore, the use of a combination of hair characteristics to differentiate species has been shown to be more useful than the use of one characteristic (Day 1966; Mukherjee 1994; Meyer *et al.* 2002; Kuhn & Meyer 2010) and may need incorporating into the approach. This will improve the rigour of the system and possibly increase the accuracy of identification to a reliable level.

CHAPTER 5

GENERAL DISCUSSION

This study served as the first of its kind to qualitatively describe the diet of black-backed jackal over a one-year period, on two land-use types utilising scat analysis in the Eastern Cape, South Africa. Seasonal trends in the dietary composition were evident and land-use type appeared to influence the types and frequency of prey items consumed. These findings are in agreement with other studies describing the effects of season and land-use on black-backed jackal diet in the southern African sub-region (Rowe-Rowe 1975, 1976; Stuart 1976; Rowe-Rowe 1983; Bussiahn 1997; Kaunda & Skinner 2003; Loveridge & Macdonald 2003; Klare *et al.* 2010).

In order to make informed decisions regarding the effective conservation and management of a predator species, a sound understanding of its ecology is necessary (Mills & Schenk 1992; Gittleman 1996). Specifically, knowledge of the trophic behaviour of a carnivore is particularly important as they frequently play a major role in limiting or regulating populations of prey species (Estes 1996; Mech 1996; Manfredi *et al.* 2004). The aspects of the trophic biology of the black-backed jackal described in this study form part of such ecology and are therefore imperative to understanding its role as a generalist predator in the thicket biome of the Eastern Cape Province (Mills 1996).

The influence of generalist mammalian predators on prey population dynamics has been well documented (Murdoch 1969; Hanski *et al.* 1991; Korpimäki & Krebs 1996; Leckie *et al.* 1998;

Hanski *et al.* 2001; Dell'Arte *et al*. 2007). However, much of this research has focussed on the well known population cycles of rodents in the northern hemisphere and the central premise that predator dietary switching controls population fluctuations (Andersson & Erlinge 1977; Steen *et al.* 1990; Hanski *et al.* 1991; Krivan 1996; van Baalen *et al.* 2001; Korpimäki *et al.* 2002; Ma *et al.* 2003; Sundell *et al.* 2003). According to Williams *et al.* (2004), although many of these studies have used an experimental approach with invertebrate or small vertebrate models, it is the large mammalian predators which are expected to place the greatest pressure on their prey populations. However, there is comparatively little data for large African carnivore species (Sinclair 1985; Mills & Schenk 1992; Viljoen 1993; Höner *et al*. 2002; Owen-Smith & Mills 2008). This is because direct experimentation using large mammalian predators is difficult and accurate data can usually only be gathered through careful observation of natural experiments (Mills 1996; Radloff & Du Toit 2004; Owen-Smith & Mills 2008; Randa *et al.* 2009).

Top mammalian predators are also considered to be major determinants of the trophic structure and biodiversity of terrestrial ecosystems (McLaren & Peterson 1994; Palomares & Caro 1999; Saether 1999; Terborgh *et al.* 2001; Sinclair *et al.* 2003; Hebblewhite *et al.* 2005; Elmhagen & Rushton 2007; Elmhagen *et al.* 2010). Although the black-backed jackal is typically referred to as a meso-predator (Smithers 1983; Skinner & Chimimba 2005; van der Merwe *et al.* 2009), in terrestrial ecosystems where widespread extinction or removal of large, apex predators has occurred, this species may become the top predator (Avenant & Nel 2002). Moreover, Klare *et al.* (2010) recommends that black-backed jackals should be considered members of the large carnivore guild when attempting to explain ungulate population dynamics.

Due to the lack of large (> 15 kg) predators, the black-backed jackal has become a top predator on three of the four study sites. As a result, black-backed jackals may have modified their predatory habits such that more hunting of adult ungulates is occurring (Klare *et al.* 2010). This was highlighted by Klare *et al.* (2010) who documented significant predatory impacts by black-backed jackals on certain ungulate populations on two game farms, void of large predators, in the Northern Cape Province, South Africa. The prevalence of ungulates in the diet of black-backed jackals in this study therefore serves as important information for those wildlife managers identifying large ungulates susceptible to jackal predation (Klare *et al.* 2010). Moreover, the prevalence of livestock in the diet of farmland jackal is also important information for those farmers attempting to determine which predators are responsible for the killing of their livestock and the extent of the damage (Rowe-Rowe 1975, 1976; Roberts 1986). However, caution should be exercised when extrapolating the results from this study to quantify predation as the qualitative measures utilised here (frequency of occurrence) do not provide a sufficient measure of individuals consumed (Ciucci *et al.* 1996; Lanszki *et al.* 2006; Klare *et al.* 2010, 2011).

The lack of large predators in these regions may also lead to meso-predator release (Soulé *et al.* 1988; Elmhagen & Rushton 2007). The meso-predator release hypothesis describes a population explosion of meso-predators occurring in association with the removal of apex predators from an ecosystem (Soulé *et al.* 1988; Crooks & Soulé 1999; Rogers & Caro 1998). The increased abundances of medium-sized predators can have detrimental effects on prey communities and can influence ecosystem functioning (Crooks & Soulé 1999; Sovada *et al.* 1995; Palomares *et al.* 1995; Rogers & Caro 1998). It is plausible that meso-predator release has occurred on three of the four study sites in my study (due to the lack/removal of large predators) and as a result, the black-backed jackals occurring in these areas may have detrimentally affected the prey communities. The continued predation by meso-predators on both the adults and neonates of certain ungulates may gradually reduce their populations by slowing recruitment (Berger *et al.* 2008). Furthermore, this predation pressure may be more significant for 'hider' species compared with 'followers' as the searching behaviour of black-backed jackal is adapted to find concealed fawns (Lamprecht 1978; Estes 1991).

However, although it was reasonably assumed by Klare *et al.* (2010) that black-backed jackals were hunting both the adults and the young of certain ungulates (particularly springbok) in an area void of large predators, this behaviour has also been recorded by Lamprecht (1978) and McKenzie (1990) in areas where large predators are present. This study may therefore indicate that black-backed jackals hunt more often in this region than in other areas. However, the scat analysis method utilised in this study is not capable of determining whether these mammalian prey items were hunted or scavenged (Mills 1996). On this basis, further studies investigating the hunting behaviour of black-backed jackals need to be conducted in this region to determine whether, in the absence of large predators, black-backed jackals hunt larger prey (Klare *et al.* 2010).

Elmhagen & Rushton (2007) indicated that both top-down (interspecific competition) and bottom-up effects (ecosystem productivity) are important determinants in meso-predator release. Terborgh *et al.* (1999) suggested that over-abundant meso-predator populations could be managed by the reintroduction of top predators to re-establish top-down effects. However, it cannot be assumed that reintroducing large, apex predators will have the same effect in all ecosystems as the relative influence of top-down and bottom-up regulation depends on the bio-climatic region, the underlying meso-predator dynamics and ecosystem productivity (Elmhagen & Rushton 2007). Moreover, the impact of top predators on ecosystem structures depends largely on top predator densities (Elmhagen & Rushton 2007). Proper trophic cascades in terrestrial ecosystems (i.e. cascade effects extending from top predator to the vegetation level) have only been shown for wolves in North American national parks (McLaren & Peterson 1994; Hebblewhite *et al.* 2005). Furthermore, these are unique cases of large, mostly pristine ecosystems. By contrast, the reserve sites in this study were neither pristine nor sufficiently large to sustain unmanaged populations of large predators (Hunter 1998; Bissett 2007). Thus, if black-backed jackals have undergone meso-predator release in the Eastern Cape, reintroducing top predators at appropriate densities in order to restore the top-down trophic cascade may not be feasible.

Secondary options include implementing meso-predator control measures in order to mimic the top-down effects of interference competition (Berger & Gese 2007) and/or intraguild predation (Polis & Holt 1992). However, trial assessments would have to be conducted to determine the extent of the control measures implemented. Moreover, although both the reintroduction of top predators and the implementation of meso-predator control measures have been to shown to restore ecosystem stability, very often a combination of these measures provides the best results (Elmhagen & Rushton 2007).

The bottom-up effects such as ecosystem productivity are influenced in this study by land-use type. On the farmlands, the anthropogenic influence on the land has resulted in what may be perceived as an increase in ecosystem productivity due to farming activities including irrigation, fertilising, cropping and the introduction of livestock (Elmhagen & Rushton 2007). Very often this increases prey abundance (e.g. livestock and small mammals) and alters prey composition (Caro 2001, 2002; Wallgren *et al.* 2009). These changes further influence the diet of the black-backed jackals as seen in this study and may lead to a population increase (Elmhagen & Rushton 2007). Although the restoration of top predator populations may buffer against anthropogenically induced changes and facilitate the preservation of species at lower trophic levels (Elmhagen & Rushton 2007), this may only be feasible on reserves and not farmlands.

I recommend that future research on black-backed jackals in the Eastern Cape Province should determine measures of prey preference (Kruger *et al.* 1999; Atkinson *et al.* 2002; Pole *et al.* 2004; Garrot *et al.* 2007; Marucco *et al.* 2008; Hayward *et al.* 2006a & b) in conjunction with quantitatively describing their diet (Ciucci *et al.* 1996; Mills 1996; Zabala & Zuberogoitia 2003; Klare *et al.* 2010, 2011). Determining prey preferences by linking the measured abundances of different prey items with those recorded in the diet (Murdoch 1969; Atkinson *et al.* 2002; Pole *et al.* 2004; Hayward & Kerley 2005; Garrot *et al.* 2007; Marucco *et al.* 2008) will allow for a more detailed understanding of what prey items are selected on different land use types and during different seasons (Hayward & Kerley 2005). Quantitatively describing the diet of black-backed jackal (e.g. using biomass models) provides an indication of the relative importance of each dietary item and thus provides more biological insight into its trophic habits (Ciucci *et al.* 1996; Lanszki *et al.* 2006; Klare *et al.* 2011). At the same time, I would further recommend the continued testing of diet assessment techniques such as the image identification software used in this study.

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APPENDICES

Appendix A: The dietary composition of black-backed jackals on the Great Fish River Reserve and Connaught farm from November 2009 to October 2010 expressed as percentage frequency of occurrence (% F0) and percentage relative frequency of occurrence (% RFO) (*n* = number of scats analysed).

Appendix B: The dietary composition of black-backed jackals on Shamwari Private Game Reserve and Sweetkloof farm from November 2009 to October 2010 expressed as percentage frequency of occurrence (% F0) and percentage relative frequency of occurrence (% RFO) (*n* = number of scats analysed).

Appendix A: The dietary composition of black-backed jackals on the Great Fish River Reserve and Connaught farm from November 2009 to October 2010 expressed as percentage frequency of occurrence (% F0) and percentage relative frequency of occurrence (% RFO). *n* = number of scats analysed.

Prey category	**Great Fish River Reserve**								**Connaught Farm**							
	Summer (*n* = 97)		**Autumn (*n* = 72)**		**Winter (*n* = 80)**		**Spring (*n* = 61)**		**Summer (*n* = 20)**		**Autumn (*n* = 21)**		**Winter (*n* = 10)**		**Spring (*n* = 8)**	
	%		**%**		**%**		**%**		**%**		**%**		**%**		**%**	
	FO	**RFO**	**FO**	**RFO**	**FO**	**RFO**	**FO**	**RFO**	**FO**	**RFO**	**FO**	**RFO**	**FO**	**RFO**	**FO**	**RFO**
Birds	**1.0**	**0.4**	**2.8**	**1.0**	**3.8**	**1.5**	**3.3**	**1.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Reptiles	**3.1**	**1.2**	**4.2**	**1.5**	**0.0**	**0.0**	**3.3**	**1.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Vegetation	**76.3**	**30.1**	**72.2**	**26.3**	**92.5**	**36.1**	**98.4**	**38.7**	**75.0**	**38.5**	**76.2**	**34.0**	**80.0**	**42.1**	**37.5**	**23.1**
Fruit / seeds	**15.5**	**6.1**	**51.4**	**18.7**	**33.8**	**13.2**	**21.3**	**8.4**	**0.0**	**0.0**	**19.1**	**8.5**	**0.0**	**0.0**	**12.5**	**7.7**
Acacia karroo	1.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	7.7
Carissa haematocarpa	0.0	0.0	10.1	3.7	3.1	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mystroxylon aethiopicum	1.0	0.4	1.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diospyros lycioides	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grewia robusta	1.0	0.4	31.3	11.4	21.5	8.4	13.7	5.4	0.0	0.0	19.1	8.5	0.0	0.0	0.0	0.0
Maerua cafra	1.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Murraya paniculata	2.9	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pappea capensis	5.8	2.3	1.1	0.4	1.0	0.4	3.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Putterlickia pyracantha	0.0	0.0	1.1	0.4	1.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhoicissus digitata	1.9	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified	1.0	0.4	6.7	2.4	7.2	2.8	4.6	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Invertebrate	**66.0**	**26.0**	**55.6**	**20.2**	**37.5**	**14.6**	**55.7**	**21.9**	**20.0**	**10.3**	**38.1**	**17.0**	**20.0**	**10.5**	**12.5**	**7.7**
Insecta	*62.7*	*24.7*	*53.4*	*19.4*	*37.5*	*14.6*	*53.4*	*21.0*	*20.0*	*10.3*	*38.1*	*17.0*	*20.0*	*10.5*	*12.5*	*7.7*
Blattaria	17.1	6.7	17.8	6.5	12.9	5.0	26.7	10.5	0.0	0.0	12.7	5.7	0.0	0.0	6.3	3.9
Orthoptera	6.5	2.6	11.1	4.0	2.6	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coleoptera	39.1	15.4	24.5	8.9	22.0	8.6	26.7	10.5	20.0	10.3	25.4	11.3	20.0	10.5	6.3	3.9
Arachnida	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.2*	*0.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Scorpiones	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diplopoda	*2.4*	*1.0*	*2.2*	*0.8*	*0.0*	*0.0*	*1.2*	*0.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Spirostreptida	2.4	1.0	2.2	0.8	0.0	0.0	1.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified	*0.8*	*0.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Mammal	**91.8**	**36.2**	**88.9**	**32.3**	**88.8**	**34.6**	**72.1**	**28.4**	**100.0**	**51.3**	**90.5**	**40.4**	**90.0**	**47.4**	**100.0**	**61.5**

Lagomorpha	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
scrub hare	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rodentia	*7.3*	*2.9*	*10.8*	*3.9*	*7.1*	*2.8*	*2.9*	*1.1*	*12.0*	*6.2*	*7.2*	*3.2*	*0.0*	*0.0*	*8.0*	*4.9*
Cape porcupine	0.0	0.0	3.6	1.3	0.0	0.0	0.0	0.0	4.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0
springhare	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	4.9
four-striped grass mouse	0.0	0.0	3.6	1.3	7.1	2.8	2.9	1.1	8.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0
Natal multimammate mouse	3.7	1.4	3.6	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
vlei rat	3.7	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	1.6	0.0	0.0	0.0	0.0
pouched mouse	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	1.6	0.0	0.0	0.0	0.0
house rat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carnivora	*29.4*	*11.6*	*17.8*	*6.5*	*28.4*	*11.1*	*46.1*	*18.2*	*40.0*	*20.5*	*25.3*	*11.3*	*0.0*	*0.0*	*28.0*	*17.2*
black-backed jackal	29.4	11.6	17.8	6.5	28.4	11.1	46.1	18.2	40.0	20.5	25.3	11.3	0.0	0.0	28.0	17.2
Suiformes	*3.7*	*1.4*	*7.1*	*2.6*	*3.6*	*1.4*	*2.9*	*1.1*	*0.0*	*0.0*	*3.6*	*1.6*	*0.0*	*0.0*	*4.0*	*2.5*
common warthog	3.7	1.4	7.1	2.6	3.6	1.4	2.9	1.1	0.0	0.0	3.6	1.6	0.0	0.0	4.0	2.5
Ruminantia	*51.4*	*20.3*	*46.2*	*16.8*	*46.2*	*18.0*	*17.3*	*6.8*	*36.0*	*18.5*	*32.5*	*14.5*	*32.4*	*17.1*	*32.0*	*19.7*
Greater kudu	11.0	4.3	0.0	0.0	7.1	2.8	0.0	0.0	4.0	2.1	3.6	1.6	0.0	0.0	4.0	2.5
bushbuck	25.7	10.1	46.2	16.8	35.5	13.8	14.4	5.7	32.0	16.4	25.3	11.3	32.4	17.1	28.0	17.2
common duiker	3.7	1.4	0.0	0.0	3.6	1.4	2.9	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
springbok	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
steenbok	11.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	1.6	0.0	0.0	0.0	0.0
impala	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Livestock	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*12.0*	*6.2*	*14.5*	*6.4*	*32.4*	*17.1*	*24.0*	*14.8*
Dorper sheep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	6.2	10.9	4.8	18.0	9.5	20.0	12.3
Angora goat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	1.6	14.4	7.6	4.0	2.5
Unidentified	*0.0*	*0.0*	*7.1*	*2.6*	*3.6*	*1.4*	*2.9*	*1.1*	*0.0*	*0.0*	*7.2*	*3.2*	*0.0*	*0.0*	*4.0*	*2.5*

Appendix B: The dietary composition of black-backed jackals on Shamwari Private Game Reserve and Sweetkloof farm from November 2009 to October 2010 expressed as percentage frequency of occurrence (% F0) and percentage relative frequency of occurrence (% RFO). *n* = number of scats analysed.

	Shamwari Private Game Reserve								**Sweetkloof Farm**							
	Summer (*n* = 53)		**Autumn (*n* = 28)**		**Winter (*n* = 41)**		**Spring (*n* = 41)**		**Summer (*n* = 6)**		**Autumn (*n* = 0)**		**Winter (*n* = 15)**		**Spring (*n* = 9)**	
	%		**%**		**%**		**%**		**%**		**%**		**%**		**%**	
Prey category	**FO**	**RFO**	**FO**	**RFO**	**FO**	**RFO**	**FO**	**RFO**	**FO**	**RFO**	**FO**	**RFO**	**FO**	**RFO**	**FO**	**RFO**
Birds	**3.8**	**1.5**	**10.7**	**3.9**	**2.4**	**1.2**	**7.3**	**2.9**	**0.0**	**0.0**			**0.0**	**0.0**	**0.0**	**0.0**
Reptiles	**9.4**	**3.7**	**0.0**	**0.0**	**2.4**	**1.2**	**2.4**	**1.0**	**0.0**	**0.0**			**0.0**	**0.0**	**0.0**	**0.0**
Vegetation	**86.8**	**33.6**	**89.3**	**32.5**	**82.9**	**42.0**	**92.7**	**36.9**	**100.0**	**54.6**			**86.7**	**43.3**	**60.0**	**42.9**
Fruit / seeds	**18.9**	**7.3**	**35.7**	**13.0**	**4.9**	**2.5**	**4.9**	**1.9**	**0.0**	**0.0**			**13.3**	**6.7**	**0.0**	**0.0**
Acacia karroo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0
Carissa haematocarpa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0
Mystroxylon aethiopicum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0
Diospyros lycioides	18.9	7.3	35.7	13.0	4.9	2.5	0.0	0.0	0.0	0.0			6.7	3.4	0.0	0.0
Grewia robusta	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.6	0.0	0.0			6.7	3.4	0.0	0.0
Maerua cafra	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.6	0.0	0.0			0.0	0.0	0.0	0.0
Murraya paniculata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0
Pappea capensis	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.6	0.0	0.0			0.0	0.0	0.0	0.0
Putterlickia pyracantha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0
Rhoicissus digitata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0
Unidentified	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0
Invertebrate	**47.2**	**18.3**	**57.1**	**20.8**	**19.5**	**9.9**	**75.6**	**30.1**	**16.7**	**9.1**			**6.7**	**3.3**	**20.0**	**14.3**
Insecta	*20.0*	*10.3*	*38.1*	*17.0*	*20.0*	*10.5*	*12.5*	*7.7*	*13.3*	*6.9*			*20.0*	*10.5*	*12.5*	*7.7*
Blattaria	4.0	2.1	10.0	4.5	7.5	3.9	2.2	1.4	6.7	3.4			0.0	0.0	4.2	2.6
Orthoptera	2.0	1.0	0.0	0.0	0.0	0.0	0.3	0.2	0.0	0.0			0.0	0.0	0.0	0.0
Coleoptera	14.0	7.2	28.1	12.5	12.5	6.6	9.9	6.1	6.7	3.4			20.0	10.5	8.3	5.1
Arachnida	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*6.7*	*3.4*			*0.0*	*0.0*	*0.0*	*0.0*
Scorpiones	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	3.4			0.0	0.0	0.0	0.0
Diplopoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0
Spirostreptida	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0
Unidentified	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*			*0.0*	*0.0*	*0.0*	*0.0*
Mammal	**92.5**	**35.8**	**82.1**	**29.9**	**85.4**	**43.2**	**68.3**	**27.2**	**66.7**	**36.4**			**93.3**	**46.7**	**60.0**	**42.9**

Lagomorpha	*11.1*	*4.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
scrub hare	11.1	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rodentia	*29.6*	*11.4*	*19.7*	*7.2*	*17.0*	*8.7*	*8.2*	*3.3*	*0.0*	*0.0*	*11.2*	*5.6*	*9.6*	*6.9*
Cape porcupine	3.7	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
springhare	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
four-striped grass mouse	11.1	4.3	0.0	0.0	10.2	5.2	8.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0
Natal multimammate mouse	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
vlei rat	14.8	5.7	16.4	6	0.0	0.0	0.0	0.0	0.0	0.0	11.2	5.6	9.6	6.9
pouched mouse	0.0	0.0	0.0	0.0	6.8	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
house rat	0.0	0.0	3.3	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carnivora	*22.2*	*8.6*	*36.1*	*13.2*	*44.4*	*22.5*	*19.1*	*7.6*	*29.3*	*16.0*	*22.4*	*11.2*	*14.4*	*10.3*
black-backed jackal	22.2	8.6	36.1	13.2	44.4	22.5	19.1	7.6	29.3	16	22.4	11.2	14.4	10.3
Suiformes	*3.7*	*1.4*	*0.0*	*0.0*	*3.4*	*1.7*	*5.5*	*2.2*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
common warthog	3.7	1.4	0.0	0.0	3.4	1.7	5.5	2.2	0.0	0.0	0.0	0.0	0.0	0.0
Ruminantia	*18.5*	*7.2*	*9.9*	*3.6*	*17.1*	*8.6*	*27.3*	*10.9*	*13.3*	*7.3*	*26.1*	*13.1*	*19.2*	*13.7*
Greater kudu	3.7	1.4	3.3	1.2	0.0	0.0	0.0	0.0	5.3	2.9	0.0	0.0	0.0	0.0
bushbuck	7.4	2.9	6.6	2.4	13.7	6.9	16.4	6.5	8	4.4	26.1	13.1	14.4	10.3
common duiker	7.4	2.9	0.0	0.0	0.0	0.0	10.9	4.4	0.0	0.0	0.0	0.0	4.8	3.4
springbok	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
steenbok	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
impala	0.0	0.0	0.0	0.0	3.4	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Livestock	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*2.7*	*1.1*	*18.7*	*10.2*	*33.6*	*16.8*	*14.4*	*10.3*
Dorper sheep	0.0	0.0	0.0	0.0	0.0	0.0	2.7	1.1	18.7	10.2	33.6	16.8	14.4	10.3
Angora goat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified	*7.4*	*2.9*	*16.4*	*6*	*3.4*	*1.7*	*5.5*	*2.2*	*5.3*	*2.9*	*0.0*	*0.0*	*2.4*	*1.7*